NASA

Technology For Space Station Evolution— Proceedings

Office of Aeronautics and Space Technology

DISPLAY 93N27704/2
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RPT#: NASA-TM-108725 NAS 1.15:108725   90/00/00   544 PAGES   UNCLASSIFIED
DOCUMENT
UTTL: Technology for Space Station Evolution. Volume 2: Data Management
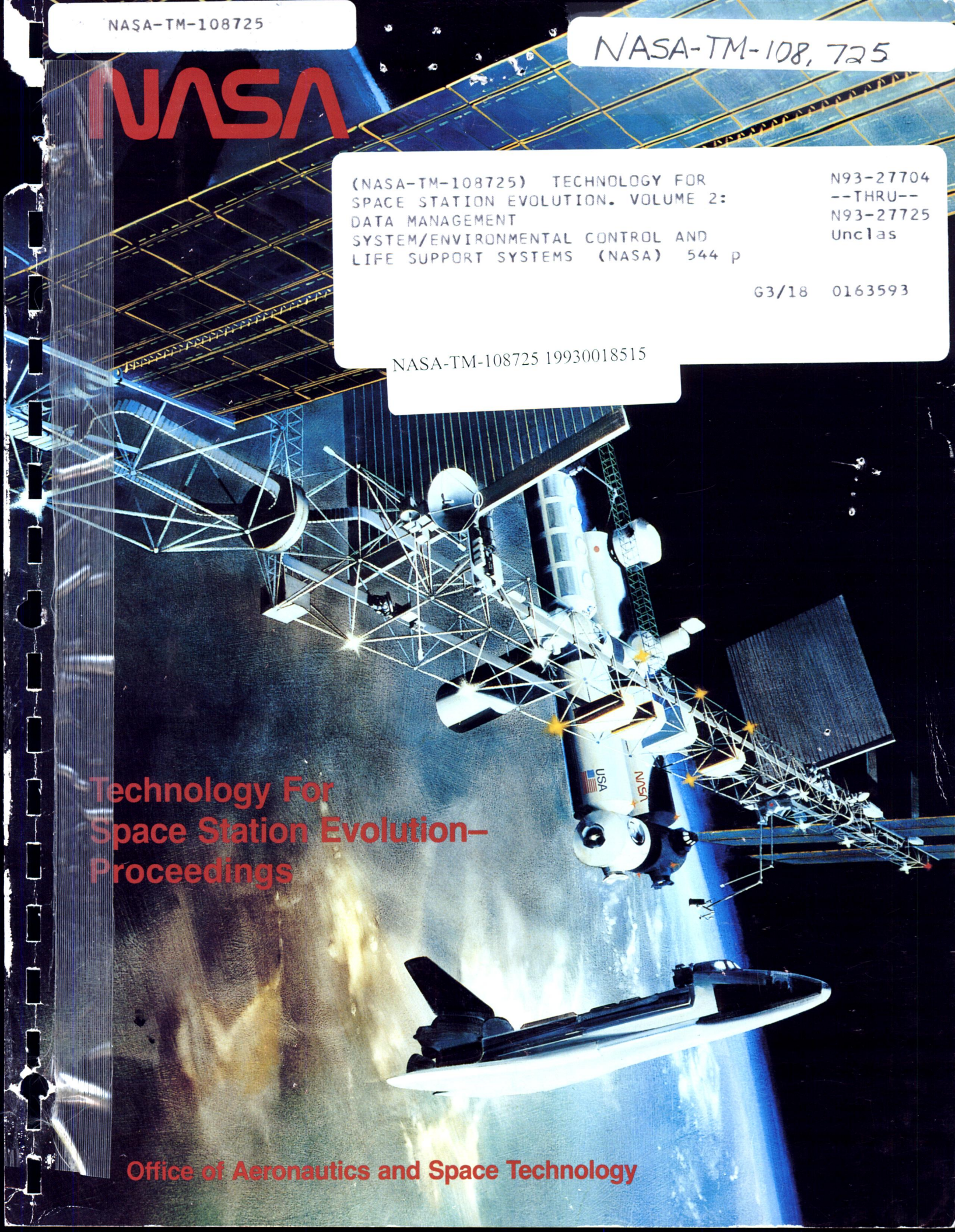   System/Environmental Control and Life Support Systems
CORP: National Aeronautics and Space Administration, Washington, DC.
SAP: Avail: CASI HC A23/MF A04; 1 functional color page
CIO: UNITED STATES   Workshop held in Dallas, TX, 16-19 Jan. 1990   Original
      contains color illustrations
MAJS: /*AEROSPACE ENGINEERING/*SPACE STATION FREEDOM/*SPACE STATION STRUCTURES/*
      SPACECRAFT DESIGN
MINS: / CONFERENCES/ DATA MANAGEMENT/ ENVIRONMENTAL CONTROL/ LIFE SUPPORT
      SYSTEMS/ MANAGEMENT SYSTEMS
ANN: NASA's Office of Aeronautics and Space Technology conducted a workshop on
      technology for space station evolution 16-19 Jan. 1990. The purpose of the
      workshop was to collect and clarify Space Station Freedom technology
      requirements for evolution and to describe technologies that can
      potentially fill those requirements. These proceedings are organized into
      an Executive Summary and Overview and five volumes containing the
      Technology Discipline Presentations. Volume 2 consists of the technology
      discipline sections for the Data Management System and the Environmental
      Control and Life Support Systems. For each technology discipline, there is

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a Level 3 subsystem description, along with the invited papers. For
individual titles, see N93-27705 through N93-27725.

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FOREWORD

Space Station *Freedom*, now under development, is a manned low Earth orbit facility which will become part of the space infrastructure. Starting in the mid 1990s, *Freedom* will support a wide range of activities, including scientific research, technology development, commercial ventures and, eventually, serve as a transportation node for space exploration. While the initial facility will not be capable of meeting all requirements, the space station will evolve over time as requirements and on-board activities mature and change. The space station design, therefore, allows for evolution to:
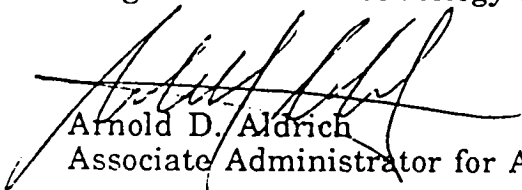
- expand capability,
- increase efficiency, and
- add new functions.

It is anticipated that many of the evolutionary changes will be accomplished through on-orbit replacement of systems, subsystems, and components as technology advances. Therefore, technology development is critical to ensure the continuing operation and expansion of the facility.
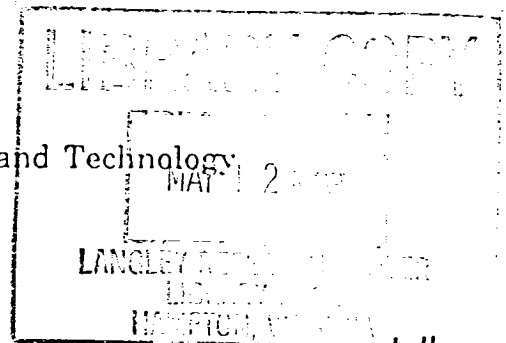
The Office of Aeronautics, Exploration and Technology (OAET) has sponsored development of many of the technologies that are now part of Space Station *Freedom'* s baseline design. Evolutionary and operational aspects of *Freedom* continue to be an important thrust of OAET's Research and Technology (R&T) efforts.

This workshop has been an important step in our understanding of the space station's baseline systems, the evolutionary scenarios including the station's role in space exploration, and the technologies that will be necessary to meet evolutionary and growth requirements.

It is anticipated that application of the information acquired through the workshop will lead to further technology development efforts to benefit *Freedom* and will lead to continued collaboration between the Space Station *Freedom* Program and the technology development community.

Arnold D. Aldrich
Associate Administrator for Aeronautics, Exploration and Technology

CLARIFICATION

Since the workshop was conducted in January of 1990, there have been some organizational changes throughout the agency. The Office of Aeronautics and Space Technology (OAST) has been reorganized to include the former Office of Exploration and is now called the Office of Aeronautics, Exploration, and Technology (OAET). Also, the Human Exploration Initiative (HEI) has been expanded and renamed the Space Exploration Initiative (SEI). Some of the materials in these proceedings were prepared after the workshop, and, therefore, references to new organizational entities and new programs may be found in certain sections.

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP
Technology Disciplines (DMS - ECLSS)

VOLUME II

INTRODUCTION

NASA's Office of Aeronautics and Space Technology (OAST) conducted a workshop on technology for space station evolution January 16-19, 1990, in Dallas, Texas. The purpose of this workshop was to collect and clarify Space Station *Freedom* technology requirements for evolution and to describe technologies that can potentially fill those requirements. OAST will use the output of the workshop as input for planning a technology program to serve the needs of space station evolution. The main product of the workshop is a set of program plans and descriptions for individual technology areas. These plans are the cumulative recommendations of the more than 300 participants, which included researchers, technologists, and managers from aerospace industries, universities, and government organizations.

The identification of the technology areas to be included, as well as the development of the program plans, was initiated by assigning NASA chairmen to the eleven technology disciplines under consideration. The disciplines are as follows:

- Attitude Control and Stabilization (ACS)

- Communications and Tracking (C&T)

- Data Management System (DMS)

- Environmental Control and Life Support Systems (ECLSS)

- Extravehicular Activity/Manned Systems (EVA/MANSYS)

- Fluid Management System (FMS)

- Power System (POWER)

- Propulsion (PROP)

- Robotics (ROBOTICS)

- Structures/Materials (STRUCT)

- Thermal Control System (THERM)

Each chairman worked with a panel of experts involved in research and development in the particular discipline. The chairmen, with the assistance of their panels, were responsible for selecting invited presentations, identifying and inviting Space Station *Freedom* Level III subsystem managers, and focusing the discussion of the participants. In each discipline session, presentations describing status of the current programs were made by the Level III subsystem managers and by OAST program managers. After invited presentations by leading industry, university, and NASA researchers, the sessions were devoted to identifying technology requirements and to planning programs for development of the identified technology areas. Particular attention was given to the potential requirements of the Human Exploration Initiative (HEI). The combined inputs of the participants in each session were incorporated into a package including an

overall discipline summary, recommendations and issues, and proposed development plans for specific technology areas within the discipline. These technology discipline summary packages were later supplemented by the chairmen and their panels to include the impact of varied funding levels on the maturity of the selected technologies. OAST will review the program plans and recommended funding levels based on available funding and overall NASA priorities and incorporate them into a new OAST initiative advocacy package for space station evolution technology.

These proceedings are organized into an Executive Summary and Overview and five volumes containing the Technology Discipline Presentations.

Volume II consists of the technology discipline sections for the Data Management System and the Environmental Control and Life Support Systems. For each technology discipline in this volume, there is a Level 3 subsystem description, along with the invited papers for that discipline.

Data Management System

Level III

Subsystem Presentation

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TECHNOLOGY FOR SPACE STATION EVOLUTION –

THE DATA MANAGEMENT SYSTEM

JANUARY 16, 1990
DALLAS, TEXAS

Space Station DMS Summary Schedule

NASA — JOHNSON SPACE CENTER

AVIONICS SYSTEMS DIVISION
Dr. L. Abbott

11/1/89
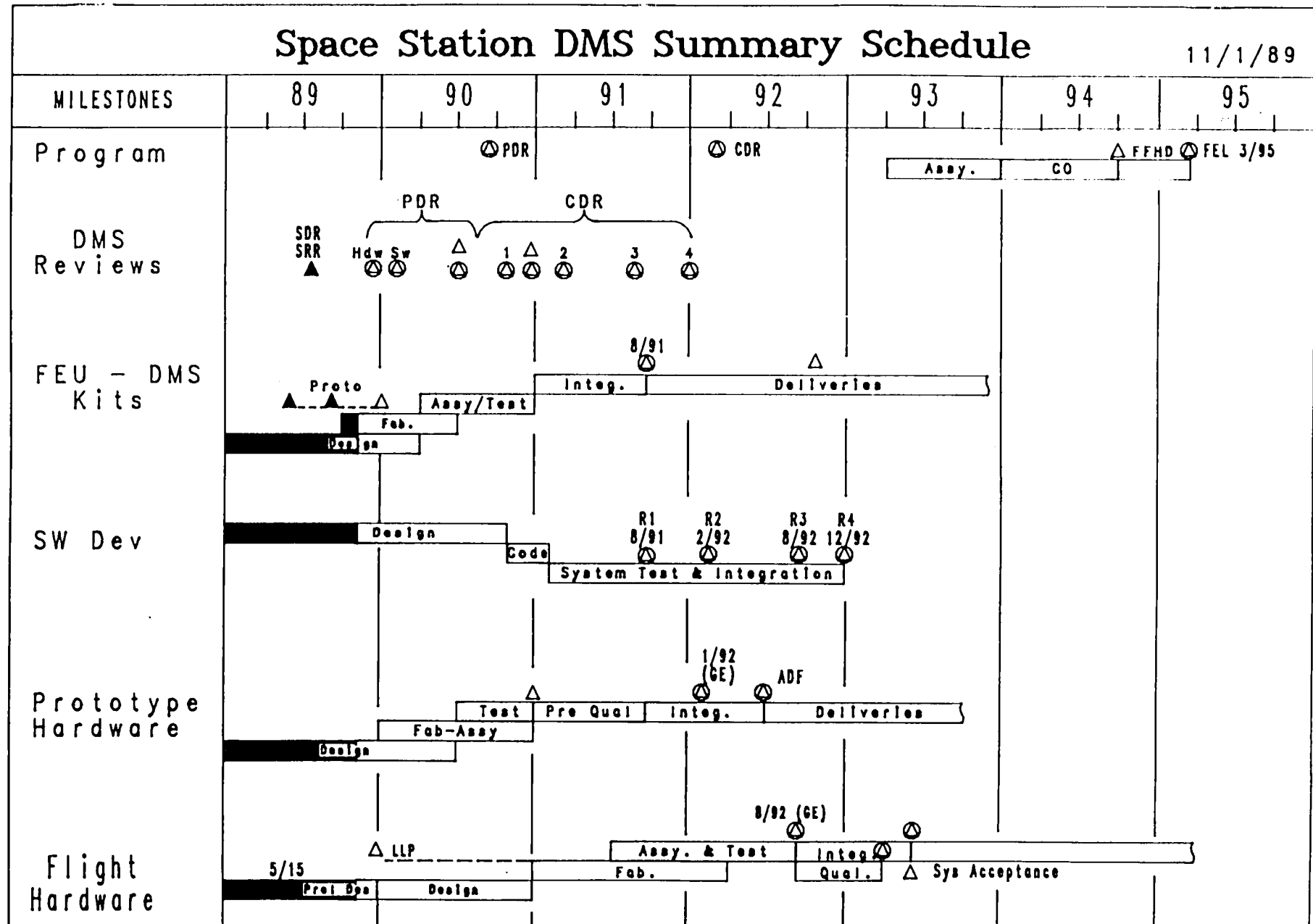
DMS ARCHITECTURE AND IMPLEMENTATION APPROACH

ON-ORBIT ARCHITECTURE

STATION OPERATOR

OMA APPLICATIONS

GND I/F

STATION/ PAYLOAD SCIENTIST

application program interface

DMS ENVIRONMENT

UNIQUE C&T/DMS INTERFACE HARDWARE

Multi-Purpose Applications Console

Multi-Purpose Applications Console

DMS

FDDI NETWORK

DMS ENVIRONMENT

DMS ENVIRONMENT

DMS ENVIRONMENT

application program interface

application program interface

application program interface

SYSTEM APPLICATIONS

SYSTEM APPLICATIONS

SYSTEM APPLICATIONS

SYSTEM HARDWARE

SYSTEM HARDWARE

SYSTEM HARDWARE

TIER 1

TIER2

PROVIDES COMMAND CONTROL CONNECTIVITY

DMS GENERIC ARCHITECTURE (AC)

DMS GENERIC ARCHITECTURE (PMC)

RING CONCENTRATOR

SDP4B
| NIA |
| EDP4 |
| EDP4 |
| BIA |

1553B
LOCAL
BUS

TGU
| TIME CODE GENERATOR |
| BIU |

RS-422

TIME DISTRIBUTION BUS

MSU
| NIA |
| EDP4 |
| EDP4 |
| SCSI |

| NIA |
| EDP4 |
| NON DMS ORU |

MPAC

| STORAGE MEDIA |

| NIA |
| EDP4 |
| EDP4 |
| FMA |
| CMA |
| SCSI |
| STORAGE MEDIA |

| DISPLAY DEVICES |

| INPUT DEVICES |

CMDM
| BIA |
| IOCU |
| I/O SET |

| BIA |
| NON-DMS ORU |

DISCRETES IN/OUT

ANALOG IN/OUT

SERIAL IN/OUT

RING CONCENTRATOR

GATEWAY
| NIA |
| EDP4 |
| ? |

INTERNATIONAL NETWORK

10

DMS BUILDING BLOCKS

NOMENCLATURE / CHARACTERISTICS

- EMBEDDED DATA PROCESSOR

  | EDP4 | (STANDARD)

  - 4 MEGABYTES MEMORY
  - 4 MIPS PROCESSING
  - 28 WATTS POWER
    CONSUMPTION

- EMBEDDED DATA PROCESSOR

  | NIA | (STANDARD)

  - 100 MBPS DATA RATE
  - 25 WATTS POWER
    CONSUMPTION

- INPUT OUTPUT CONTROL UNIT

  | IOCU |

  - STANDARD CARD FOR MDM
  - POWER CONSUMPTION
    - 7 + WATTS

DESCRIPTION

- SINGLE CARD GENERAL PURPOSE
  COMPUTER WHICH PROVIDES THE
  PROCESSING FUNCTION FOR ALL
  SPACE STATION FREEDOM HARDWARE
  CONFIGURATION ITEMS REQUIRING A
  PROCESSING CAPABILITY.

- SINGLE CARD WHICH PROVIDES THE
  FUNCTIONAL AND PHYSICAL
  CONNECTION TO THE DMS FDDI
  (FIBER DISTRIBUTED DATA INTERFACE)
  OPTICAL NETWORK AND TO THE TGDS
  (TIME GENERATION AND
  DISTRIBUTION SYSTEM)

- STANDARD CARD FOR MDM WHICH
  PROVIDES PROCESSING CAPABILITY
  AND CONTROL FUNCTIONS FOR MDM
  I/O

11

NOMENCLATURE / CHARACTERISTICS

DESCRIPTION

- STANDARD DATA PROCESSOR

NIA
EDP4
EDP4

SDP 4

- PWR CONSUMPTION ~ 104W
- INTERFACE TO NETWORK
- 4 MEGABYTES MEMORY
- 4 MIPS PROCESSING SPEED
- SOFTWARE SUPPORTED
  - OS/RTE
  - NOS
  - USE
  - DCS
  - DMS SM
  - OMA
  - APPLICATIONS

- GENERAL PURPOSE COMPUTER WHICH PROVIDE DATA PROCESSING RESOURCES TO SUPPORT CONTROL AND MANAGEMENT OF INTEGRATED STATION FUNCTIONS AND COMMAND AND CONTROL FUNCTIONS REQUIRED BY SYSTEMS, ELEMENTS, AND PAYLOADS.

- PROVIDES INTERFACE TO DMS GLOBAL NETWORKS

12

DMS ARCHITECTURAL COMPONENTS

NOMENCLATURE / CHARACTERISTICS

- FIXED OR CUPOLA MULTIPURPOSE
  APPLICATION CONSOLE (MPAC)

NIA
EDP4
EDP4
FMA
CMA
LOCAL MASS STORAGE

→ DISPLAY DEVICES
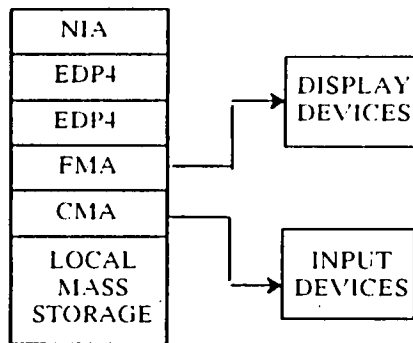
→ INPUT DEVICES

FMPAC OR CMPAC

- FMPAC POWER CONSUMPTION
  1638 WATTS

- CMPAC POWER CONSUMPTION
  969 WATTS

- FMA (FIXED MPAC ADAPTOR)
  DRIVES DISPLAYS

- CMA (COMMON MPAC
  ADAPTOR) DRIVES INPUT
  DEVICES

- SUPPORTS LOCAL MASS
  STORAGE 30 MBYTES FIXED,
  1.4 MBYTES REMOVABLE

- SOFTWARE SUPPORTED
  - SAME AS SDPR
  - PLUS?

DESCRIPTION

- PROVIDES ELECTRONIC INTERFACE BETWEEN
  APPLICATION PROGRAMS AND ONBOARD
  OPERATORS. USED FOR OPERATIONAL
  CONTROL AND MONITORING, TRAINING,
  TESTING, CAUTION & WARNING
  ANNUNCIATION AND CREW SERVICES.

- SUPPORTS VISUAL AND LOGICAL ASPECTS OF
  HUMAN COMPUTER INTERFACE USING USE
  SOFTWARE.

13

NOMENCLATURE / CHARACTERISTICS

DESCRIPTION

- MULTIPLEXER/DEMULTLIPLEXER (MDM)

```
┌─────────┐
│   BIA   │
├─────────┤
│  IOCU   │
├─────────┤
│ I/O SET │
└─────────┘
```

→ DISCRETES
  I/O

→ ANALOG I/O

→ SERIAL I/O (1553 B)
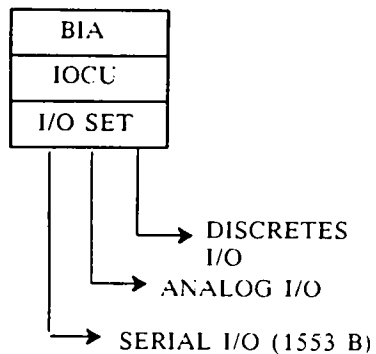
MDM

- PROVIDES CHASSIS WITH STANDARD BACKPLANE INTO WHICH I/O SETS CAN BE PLUGGED TO PERFORM REQUIRED TASKS

- 10 STANDARD CARDS ARE CURRENTLY DEFINED.

- POWER CONSUMPTION:
  IOCU CARD - 7 WATTS
  TEMP/PRESS/ANALOG - 4 WATTS
  ANALOG INPUTS (32) - 2 WATTS
  ANALOG OUTPUTS (4) - 2 WATTS
  ANALOG OUTPUTS (16) - 4 WATTS
  5V DISCRETE INPUTS - 1 WATT
  5V DISCRETE OUTPUTS - 3 WATTS
  SOLENOID DRIVER - TBD
  SERIAL I/O - TBD
  MIL STD 1553B BCU - TBD

- CAN ALSO ACCEPT USER CARDS THAT SATISFY STANDARD BACKPLANE INTERFACE

- SOFTWARE SUPPORTED - NONE

- PROVIDES INTERFACE TO SENSOR AND EFFECTORS.

- COLLECTS, REFORMATS TO DIGITAL WORDS, MULTIPLEXES AND TRANSMITS SENSOR DATA.

- RECEIVES COMMAND WORDS, DEMULTIPLEXES. ISSUES COMMANDS

DMS ARCHITECTURAL COMPONENTS

NOMENCLATURE / CHARACTERISTICS   DESCRIPTION

- MASS STORAGE UNIT (MSU)

NIA
EDP4
EDP4
SCSI
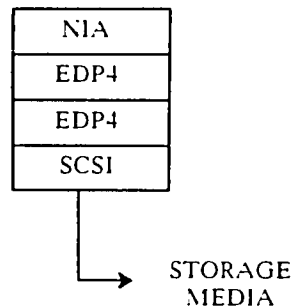
→ STORAGE
   MEDIA

- PROVIDES INTERFACE TO MAIN DMS NETWORK VIA NIA AND EDP4

- LOCAL PROCESSING CAPABILITY IN EDP4

- ALSO PROVIDES SCSI (SMALL COMPUTER SYSTEMS INTERFACE) TO STORAGE MEDIA WITH MODULAR DESIGN TO ALLOW EASY UPGRADE

- CURRENT STORAGE MEDIA IS 250 MBYTES HARD DISK

- POWER CONSUMPTION IS - 104 WATTS FOR MSU PLUS - TBD WATTS FOR STORAGE MEDIA

- SOFTWARE SUPPORTED

  -OS/RTE

  -NOS

  -DCS

  -APPLICATIONS

- PROVIDES MASS STORAGE FOR CORE AND PAYLOAD USES

- UTILIZES DIRECT ACCESS, NONVOLATILE MAGNETIC DISK MEMORY

- PROVIDES THE PROCESSING, INSTRUCTIONS, MEMORY AND I/O CAPABILITIES TO RECEIVE INPUT INFORMATION, MANIPULATE THE INFORMATION UNDER INTERNAL STORED PROGRAMS AND PROCESS THE DATA FOR STORAGE

15

DMS ARCHITECTURAL COMPONENTS

NOMENCLATURE / CHARACTERISTICS

DESCRIPTION

- EMBEDDED APPLICATIONS

NIA
EDP4
NON DMS ORU

- PROVIDES CONNECTIVITY TO 100 MBPS NETWORK
- DMS PART OF POWER CONSUMPTION = 53 WATTS
- SOFTWARE

  -SUBSET OF NOS

- PROVIDES STANDARD FUNCTIONAL AND PHYSICAL INTERFACE BETWEEN THE DMS 100 MBPS OPTICAL NETWORK AND A NON DMS PROCESSOR.

BIA
SMART SENSOR

- PROVIDES CONNECTIVITY TO 10 MBPS LOCAL BUS – LAYERS 1 AND 2 ONLY
- DMS PART OF POWER CONSUMPTION - 4 WATTS
- SOFTWARE – NONE

- PROVIDES PHYSICAL LAYER (LAYER 1) AND MEDIUM ACCESS CONTROL SUBLAYER (PARTIAL LAYER 2) PROTOCOLS BETWEEN DMS 10 MBPS LOCAL BUS AND AN INTELLEGENT HARDWARE APPLICATION.

- GATEWAY (GW)

NIA
EDP4
?

- CONNECTS 100 MBPS OPTICAL NETWORK WITH NON DMS NETWORK.
- U.S. PORTION OF POWER CONSUMPTION - 80 WATTS
- RECEIVES & DISTRIBUTES TIME INFORMATION TO NON DMS NETWORK

- THE GATEWAY PROVIDES CONNECTIVITY BETWEEN A DMS OPTICAL NETWORK AND A NON DMS NETWORK. GW TERMINATES U.S. PROTOCOLS AT ISO/OSI LAYER 2 AND PROVIDES A STANDARD LAYER 3 INTERFACE. NON-U.S. DMS CARDS MUST INTERFACE AT LAYER 3.
- IT MAY BE POSSIBLE TO UTILIZE THE DMS BNIU TO PROVIDE THIS FUNCTION IF SUFFICIENT AGREEMENTS CAN BE REACHED WITH THE INTERNATIONAL PARTNERS

16

DMS ARCHITECTURAL COMPONENTS

NOMENCLATURE / CHARACTERISTICS

DESCRIPTION

- TIME GENERATION UNIT (TGU)

```
+-------------+
|    TIME     |
|    CODE     |
|  GENERATOR  |
+-------------+
|    BIU      |
+-------------+
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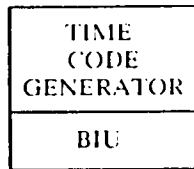
- CCCSDS SEGMENTED CODE
- ACCURATE TO + 10 MICROS
- POWER CONSUMPTION - 30 WATTS

- THE TIME GENERATION UNIT IS THE PRECISION TIME AND FREQUENCY SOURCE FOR ALL SPACE STATION FREEDOM SYSTEMS AND PAYLOADS. CONVERSION TO A CONTINUOUS UNSEGMENTED CODE PROVIDED BY DMS AT DESIGNATED PROCESSORS. TWO TGU'S AND THE TDB CONSTITUTE TGDS.

- RING CONCENTRATOR
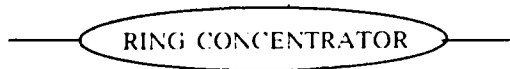
RING CONCENTRATOR

- EIGHT ATTACHMENT PORTS
- OPTICAL SIGNAL REGENERATION
- POWER CONSUMPTION - 7 WATTS

- THE RING CONCENTRATOR PROVIDES THE CONNECTIVITY FOR ALL NIU'S INTERFACING TO THE DMS OPTICAL NETWORKS. THE RC PROVIDES SWITCHING MECHANISM TO CONNECT OR BYPASS AN ORU.

- PATCH PANEL

```
+-----------------+
| •  •  •  • |
|                 |
| •  •  •  • |
|                 |
| •  •  •  • |
+-----------------+
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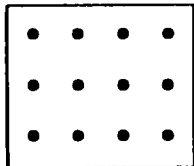
- PASSIVE DEVICE
- MANUAL OPERATION
- PROVIDES 192 PORTS
  - -32 OF WHICH PROVIDE DATA AND CONTROL FLOW TO THE C & T SIGNAL PROCESSOR (SP) (8 PORTS EACH SP, SPARE DUPLEXED FOR REDUNDANCY

- THE PATCH PANEL PROVIDES CAPABILITY FOR MANUAL SELECTION OF CONNECTIVITY FOR THE HIGH RATE FIBER OPTIC LINKS. THE PANEL IS TRANSPARENT TO BOTH THE DIRECTION AND THE FORMAT OF THE DATA.

DMS SUMMARY

BASELINE CONTENT	REBASELINE	
	PMC	AC
Distributed Architecture	More Centralized Architecture	More Distributed Architecture
Distributed Processing at Local Bus Level	Limited Processing at Local Bus Level	Increased Processing Capability at Local Bus Level
Two Types of Local Bus Capability	One Local Bus Type	Add High Performance Local Bus
Separate Payload and Core Networks	Payload & Core Networks Shared	Separate Payload and Core Bus
New Tech Displays	Use Existing Display Technology	Upgrade Displays
8 High Rate P/L Link (0 – 100 MBPS)	3 High Rate Links (0 – 100 MBPS) ZOE Recording for Core Data	8 (0 – 100 MBPS)
HARDWARE QTY: SDP – 29 EDP – 216 MDM – C – 12 MDM – 117 Bridge – 3 RC – 42	HARDWARE QTY: SDP – 16 EDP – 0 MDM – C – 59 MDM – 0 Bridge – 0 RC – 18	HARDWARE QTY: SDP – 28 EDP – 0 MDM – C – 87 MDM – 81 Bridge – 3 RC – 44

NASA
JOHNSON SPACE CENTER

AVIONICS SYSTEMS DIVISION
Dr. L. Abbott

DMS SOFTWARE SERVICES ARCHITECTURE

APPLICATION PROGRAM			
API			
USE	D C S	NOS ID* / N O S	BCS ID* / B C S
OS/RTE			

API   (Application Program Interface)

OS/RTE (Operating System/Ada Runtime Environment)

NOS   (Network Operating System)

BCS   (BUS Control System)

DCS   (Data and Command Services)

USE   (User Support Environment)
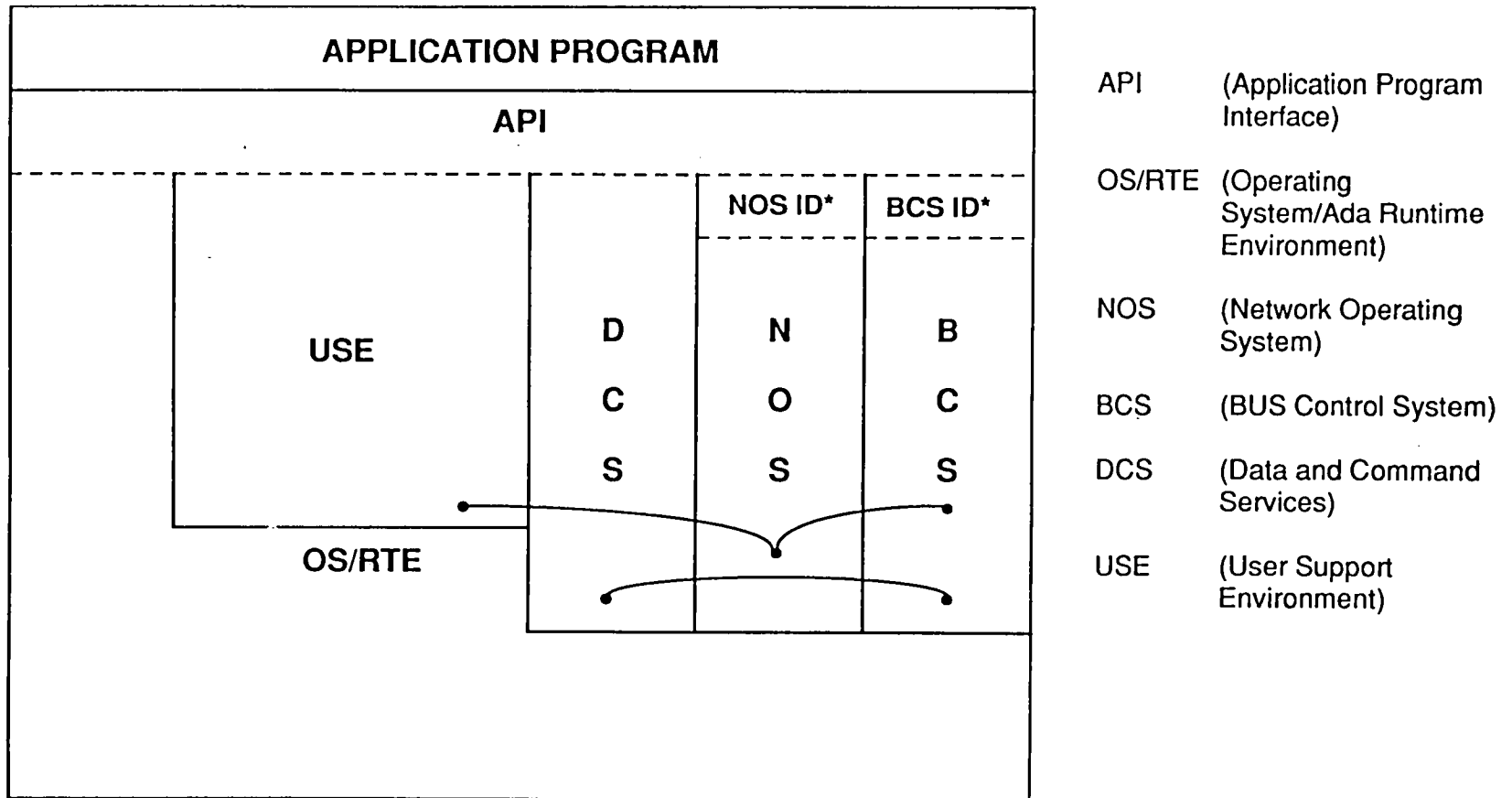
*Interface Exposed to Embedded NIU or BIU in Non DMS Processor

DMS SOFTWARE SERVICES

NOMENCLATURE / CHARACTERISTICS

- OPERATING SYSTEM/ADA RUNTIME
  ENVIRONMENT

  | OS/RTE |

- TWO PERFORMANCE CATEGORIES
  - PROCESS CONTROL
  - INFORMATION PROCESSING
- FUNCTIONS
  - INITIALIZATION
  - PROCESS MANAGEMENT
  - MEMORY MANAGEMENT
  - PROCESS COMMUNICATION
  - TIME SERVICE
  - INPUT/OUTPUT MANAGEMENT
  - FILE MANAGEMENT
  - ADA RUNTIME ENVIRONMENT
    EXTENSIONS
  - PRIVACY AND SECURITY
  - MONITOR SERVICES
  - FDIR AND RM FOR
    PROCESSORS AND I/O

DESCRIPTION

- PROVIDES MANAGEMENT, ALLOCATION, AND
  DEALLOCATION OF THE CPU, MEMORY,
  SYSTEM CLOCK, AND I/O DEVICE PROCESSING
  RESOURCES AND PROVIDES NETWORK
  TRANSPARENT INTERFACES FOR
  APPLICATION TO APPLICATION
  COMMUNICATIONS.

20

DMS SOFTWARE SERVICES (CONT)

NOMENCLATURE / CHARACTERISTICS

- NETWORK OPERATING SYSTEM

NOS

- MESSAGING SERVICES
  - CONNECTION ORIENTED
  - CONNECTIONLESS
  - BROADCAST
  - MULTICAST
  - POINT TO POINT
- SUPPORTS
  - PRIORITIZATION
  - TIME TAGGING
  - GRADE OF SERVICE
  - SECURITY & PRIVACY
  - NETWORK MANAGEMENT
  - FDIR

DESCRIPTION

- PROVIDES NETWORK COMMUNICATION FUNCTIONS FOR SYSTEMS, ELEMENTS, AND PAYLOADS PERFORMING ALL OF THE FUNCTIONS REQUIRED FOR TRANSPARENT TRANSMISSION OF USER DATA ACCROSS THE DMS NETWORK. SERVICES PROVIDED ARE LISTED IN TABLE 3.4.1.1.2.-1 OF SSP 30261, PART 3, REV D DRAFT.

21

DMS SOFTWARE SERVICES (CONT)

NOMENCLATURE / CHARACTERISTICS

DESCRIPTION

- NOMENCLATURE/FUNCTION

| DCS |

- SENSOR DATA PROCESSING
- DATA AND COMMAND DISTRIBUTION
- DATA DICTIONARY
- ARCHIVE MANAGEMENT
- CHECKPOINT MANAGEMENT
- STRUCTURED FILE SERVICE
- PRIVACY AND SECURITY
- DATA REDUNDANCY SERVICES
- INSTRUMENTATION SERVICES
- LOCAL PROCESS CONTROL

- PROVIDES DATA HANDLING SERVICES WHICH ARE COMMON ACROSS MULTIPLE SYSTEMS AND ELEMENTS

| USE |

- SOFTWARE SUPPORT FOR MPAC I/O DEVICE
- STATIC & DYNAMIC DISPLAYS
- WINDOWED VIDEO IMAGES DISPLAYS
- WINDOWED C&W DISPLAYS
- PROCEDURAL, ENGLISH-LIKE USER INTERFACE LANGUAGE (UIL)
- REMOTE TERMINAL SERVICE
- ACCESS AUTHORIZATION

- THE DMS USE PROVIDES THE ONBOARD RUNTIME ENVIRONMENT SERVICES WHICH ARE A SUBSET OF THE DEVELOPMENT TOOLS AND RUNTIME ENVIRONMENT DEFINED FOR THE SSIS HCI (HUMAN COMPUTER INTERFACE) SERVICES FOR GROUND AND ONBOARD.

22

Custom Only ◄─ ─ ─ ─ ─ ─ ─ ►│◄─ ─ ─ ─ ─ Cooperative COTS/Custom ─ ─ ─ ─ ─ ─ ─ ─►

**Custom
Ada Applications**

SM, OMA, non-DMS

**DSAR
& USE**

**COTS &
Non-Ada**

STSV

RTE Extensions

**Ada
RTE(s)**

**POSIX
OS Kernel**

NOS

HW
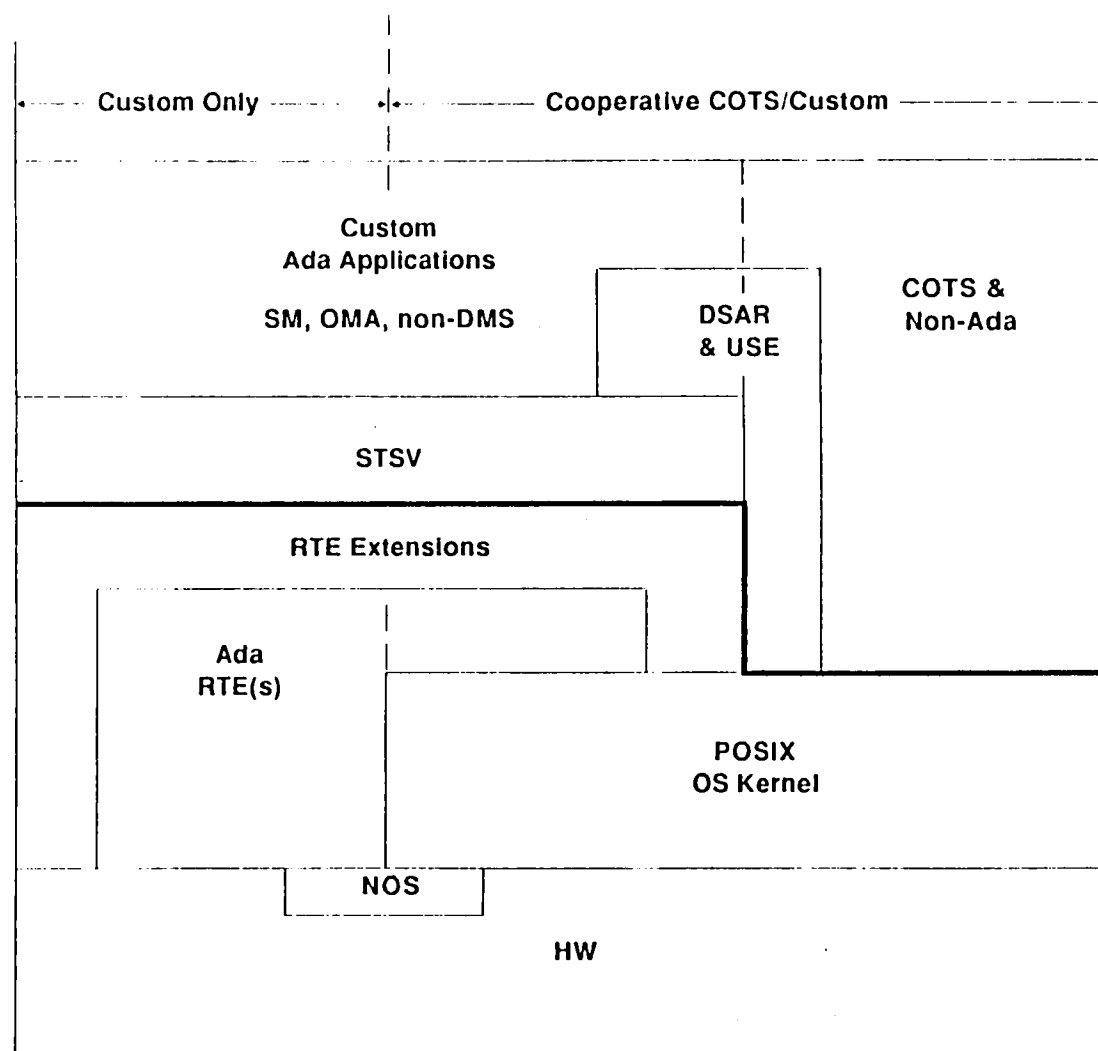
DMS Software Layering
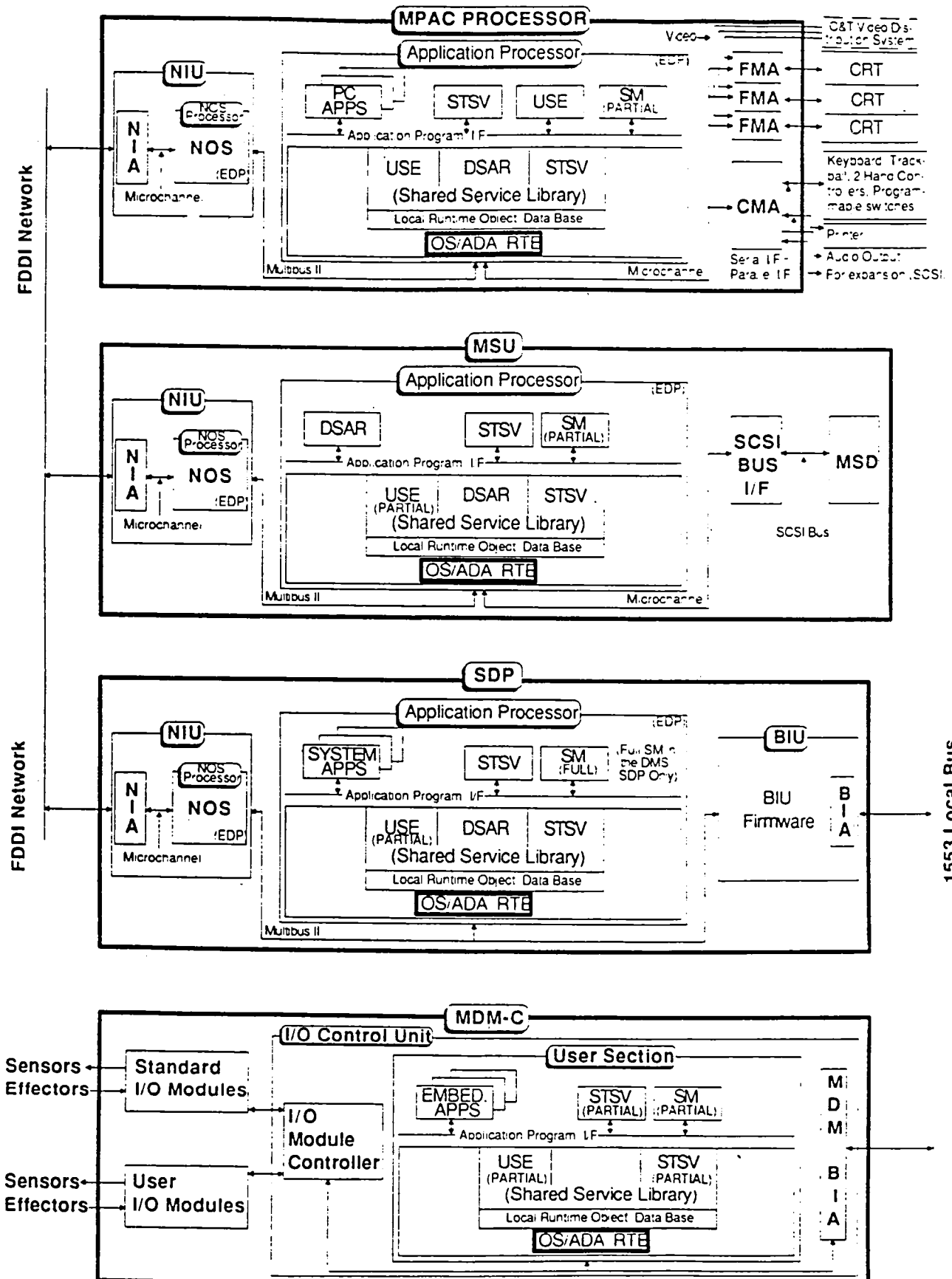
FIGURE 4.0-2. DMS Architecture Model

24
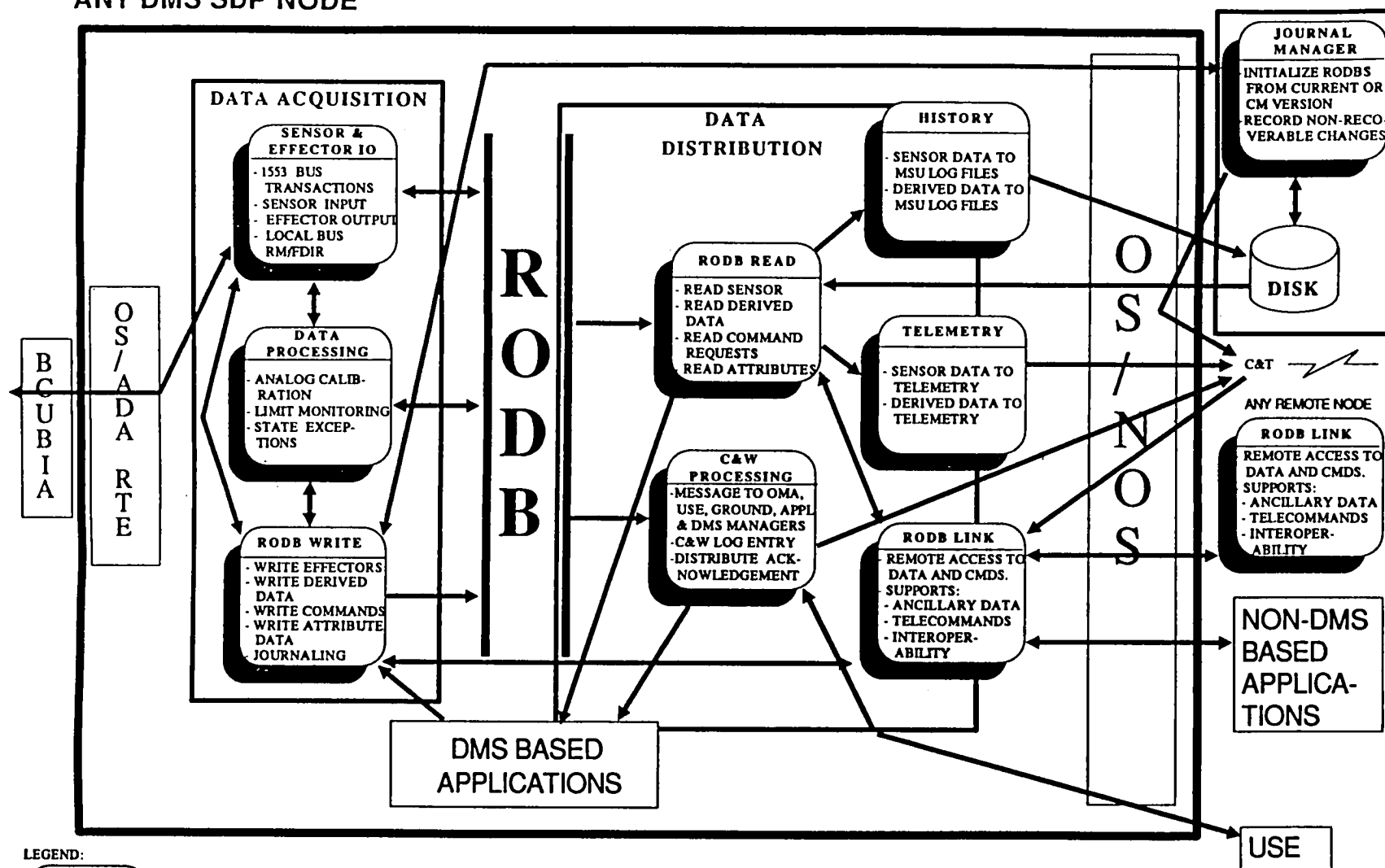
DMS STANDARD SERVICES FUNCTIONAL FLOW DIAGRAM

SDP

- 10 async BCU scan lists created by MODB manager.
- Based on user defined sample rates.
- A=10 SPS, B through K=1 SPS.
- Scan lists created to optimize bus load.

ASYNCHRONOUS I/O SCANS

T-1   T-0

APPLICATION PROCESSOR

RODB   **Asynchronous I/O Application**

A B C D E F

MDM1

START SCANS
:
OPEN D,E,F
:
READ D,E,F
:

- Async. I/O used by applications without synchronous requirements.
- Read comes from RODB (last value read-average staleness is a function of sample rate).
- Also used by STSV history, telemetry, ancillary data, CMDM displays.
- Allows optimization of bus load.
- Allows applications to be designed "event driven" by STSV limit monitoring, rate of change, etc. services.

G H I J K L

MDM2

SYNCHRONOUS I/O SCANS

LOCAL BUS

BCU/ BIA

LAST 3 SCANS

- MDM scan tables created by MODB.
- Downloaded by STSV to MDM.
- Read A 10 SPS
- Read B K 1 SPS
- Read L-Q at 10 SPS
- Coordination between MDM scan and BCU scan is possible to limit jitter.

Synchronous I/O Application

START SCAN_X, SCAN-Y
OPEN SCAN_X
OPEN SCAN_Y

READ SCAN_X
:

- Sync. I/O used by applications with synchronous requirements.
- Task is suspended at READ until I/O is complete.
- STSV processes read directly into application variables.
- Only extra overhead is storing values into RODB for asynchronous access for telemetry, history, displays, etc.

M N O P Q

MDM3

- 2 user defined BCU scan lists.
- Explicitely defined into MODB by user.
- Order of object reads explicit (L,M,N & O,P,Q)
- Rate specified by user (10 SPS in this example).
- Bus load is manually defined.

SYNCHRONOUS AND ASYNCHRONOUS I/O STANDARD SERVICES SCENARIO
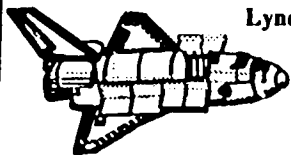
NASA
Lyndon B. Johnson Space Center
SPACECRAFT
SOFTWARE
DIVISION

OVERVIEW OF THE RUNTIME OBJECT

DATABASE

GENERAL COMMAND AND CONTROL DATA FLOW MODE - CHAOS
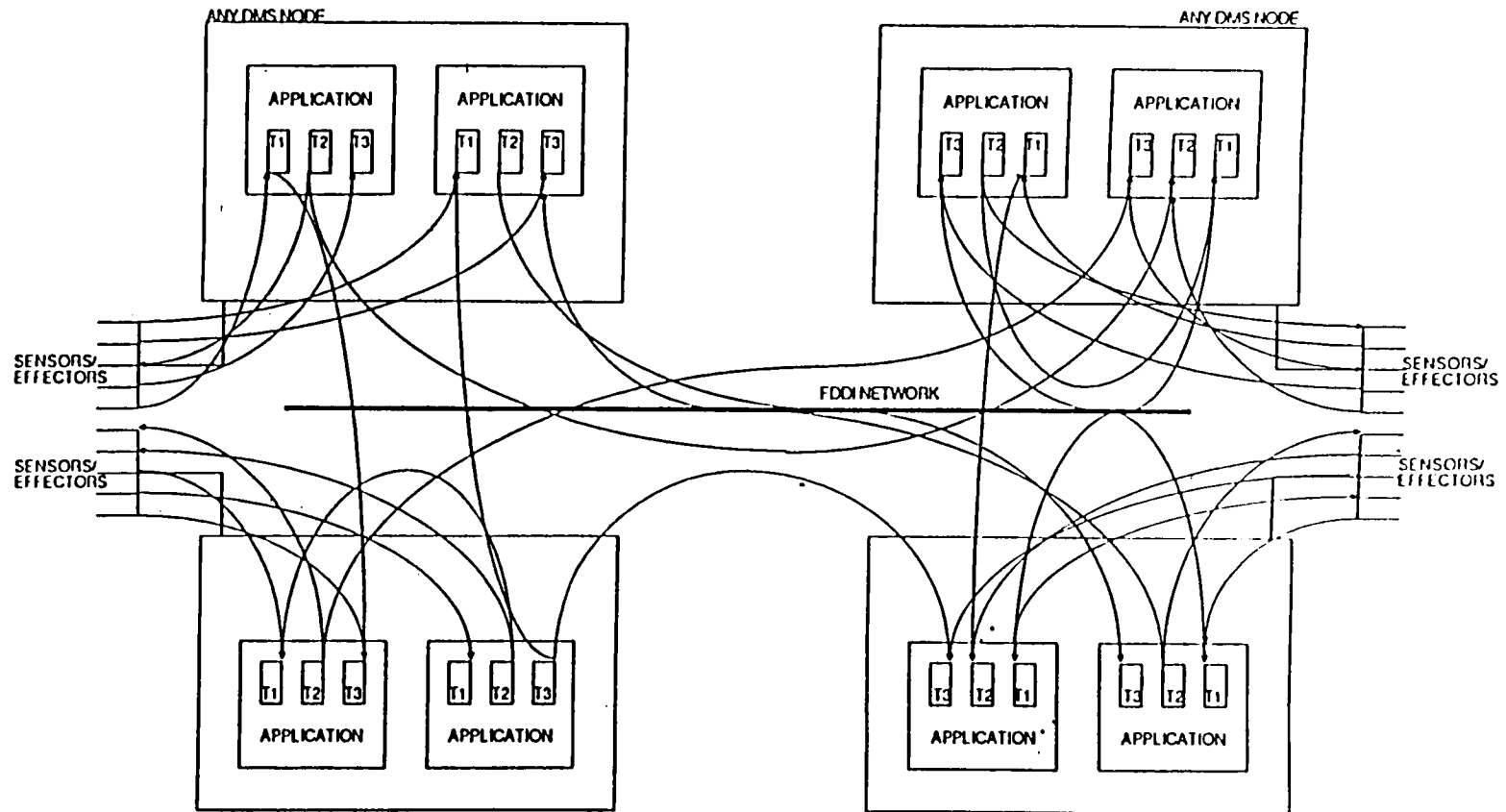
COMMAND AND CONTROL WITHOUT RODB/MODB CONCEPT WOULD MEAN:
- IPC MECHANISM FOR TASK TO TASK COMMUNICATION (PRIVATE ICDs FOR ABOVE LINES)
- NO COMMON, SYSTEM-WIDE APPROACH TO COMMAND AND CONTROL FROM OMA, DISPLAYS, GROUND
- NO COMMON, SYSTEM-WIDE APPROACH TO COMPLEXITIES OF COMMUNICATIONS
- MANUAL OVERRIDE (FROM MPAC OR GROUND) IS A NIGHTMARE OF ICD RESOLUTIONS
- IT&V WOULD BE A NIGHTMARE OF PRIVATE IPC VERIFICATION
- NO DRIVING FORCE BEHIND COMMON DATA REPRESENTATION

RODB COMMAND AND CONTROL DATA FLOW MODEL - ORDER
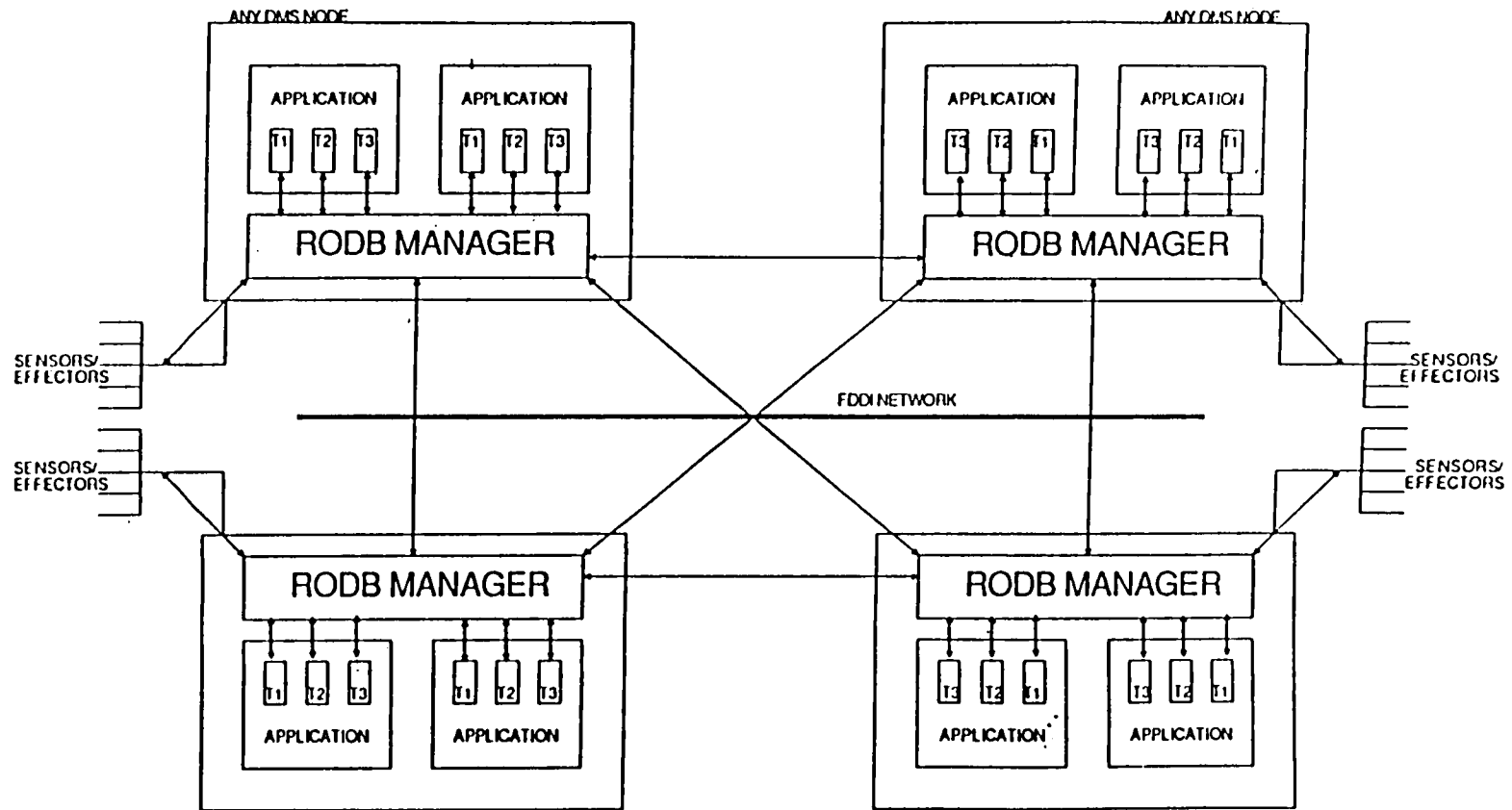
COMMAND AND CONTROL WITH RODB/MODB CONCEPT WOULD MEAN:
- ONE DMS ENGINEERED, SYSTEM-WIDE APPROACH TO COMMAND AND CONTROL
- EFFECTIVE, CONSISTENT USE OF COMMUNICATION SERVICES BY ALL APPLICATIONS
- MODB/RODB IS LIKE AN AUTOMATED ICD FOR THE WHOLE SYSTEM
- EFFECTIVE ENVIRONMENT FOR CREW COMMAND AND CONTROL DISPLAYS FOR
    NORMAL OPERATIONS AS WELL AS TROUBLE SHOOTING & MANUAL OVERRIDE
- EFFECTIVE ENVIRONMENT FOR IT&V OF FLIGHT HARDWARE AND SOFTWARE
- COMMON DATA REPRESENTATIONS ACROSS ALL APPLICATIONS

Definitions

- RODB

  o Isolates applications from the effects of data request changes resulting from:

    — Crew user interface

    — Space/ground telemetry/command

  o Provides standard services to applications for sensor/effector related processing

  o Requires applications to make data global for visibility

  o Runtime online data base

  o Contains directory, dictionary, and current values of objects

  o Contains a subset of the data in the MODB

THE RODB AS THREE KINDS OF INFORMATION

SENSOR DATA,
DERIVED/COMPUTED
DATA

CURRENT
VALUES

DIRECTORY
INFORMATION

DATA DEFINITIONS
COMMAND DEFINITIONS
EVENT DEFINITIONS

DICTIONARY
INFORMATION

RODB MANAGER
APPLICATION PROGRAM
INTERFACE (API)

MODB

31
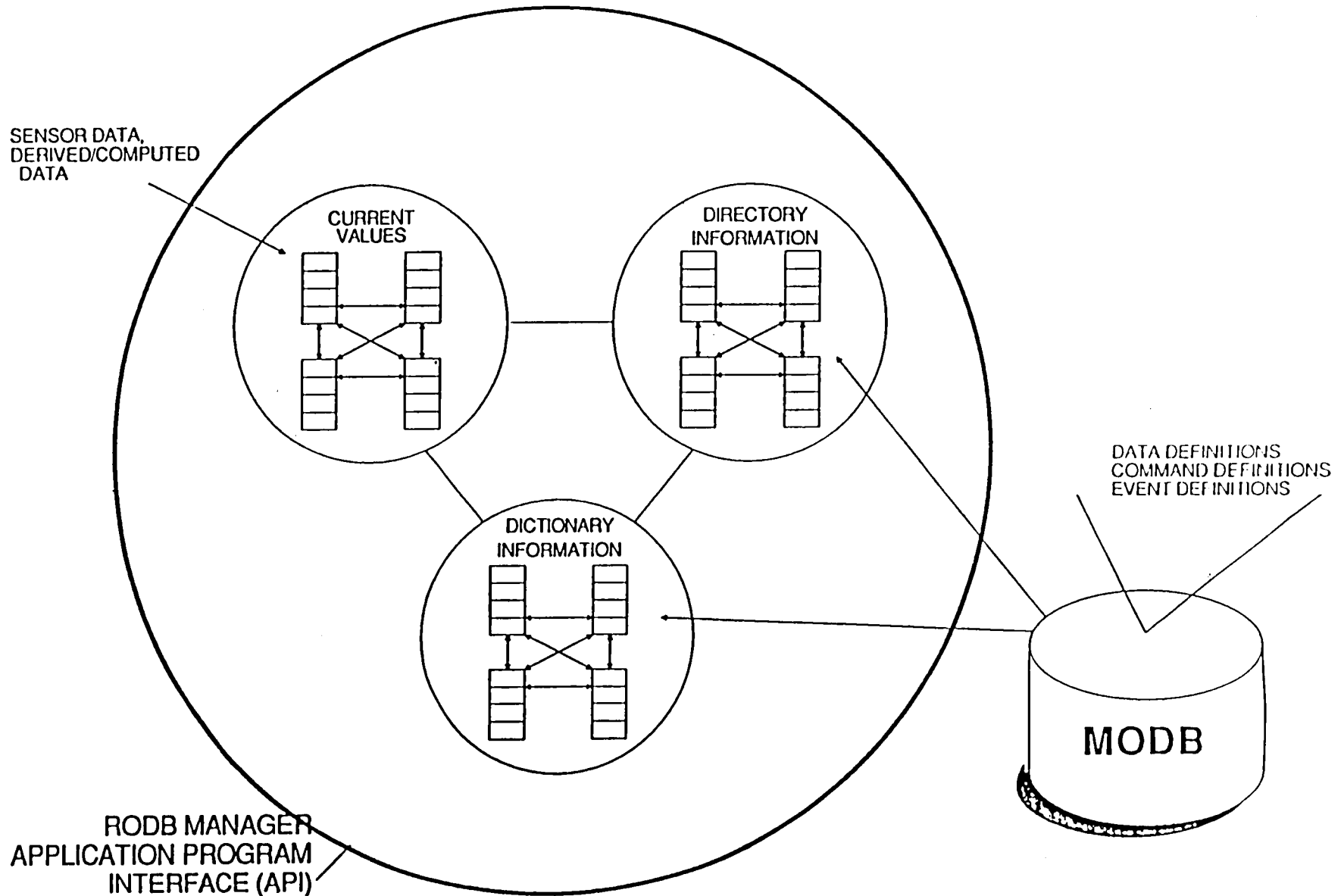
◆ **Three parts:**

1. **Description of the object (at a position in the hiererchy)**

2. **Attributes of the object:**
   → Descriptions
   → Names
   → Constraints
   → RODB and MODB information

3. **Actions on the object:**
   → Descriptions
   → Names
   → Parameters
   → Completion codes
   → Timeouts

RODB

OMA

USER SUPPORT
ENVIRONMENT

C&W MESSAGE

RODB WRITE
COMMAND

EVENT
OBJECT

RODB READ
EVENT

EVENT DRIVEN
APPLICATION

RODB
WRITE
COMMAND

RODB READ
ATTRIBUTES

RODB READ
ATTRIBUTES

S1

CAMERA
OBJECT

CONTROL
OBJECT

EFFECTORS

RODB READ
COMMAND

RODB WRITE
ATTRIBUTES

CAMERA
CONTROLLER

CYCLIC
DATA
HISTORY
LOG

SCAN
OBJECT

RODB
WRITE
CONTROL

RODB
READ
SCAN

CONTROL
APPLICATION

SENSORS

RODBMODL

33

RODB NODE MODEL

GN&C SDP

TCS SDP

BACKEND PROCESSOR

BCS NOS
OR
BIU/BIA

HOST PROCESSOR

GN&C
APPLICATION

RODB
Data
Current
values
Attribute
data

RODB
Manager

DATA
ACQUISI
TION

RODB
LINK

OS/Ada RTE

FRONTEND PROCESSOR

ISO NOS

7
6
5
4
3
2
1

FRONTEND PROCESSOR

ISO NOS

7
6
5
4
3
2
1

HOST PROCESSOR

TCS
APPLICATION

RODB
Manager

RODB
Data
Current
values
Attribute
data

RODB
LINK

DATA
ACQUISI
TION

OS/Ada RTE

BACKEND PROCESSOR

BCS NOS
OR
BIU/BIA

BACKEND BUS
SENSORS &
EFFECTORS

FDDI NETWORK

BACKEND BUS
SENSORS &
EFFECTORS

MPAC

NON DMS PROCESSOR

HOST PROCESSOR

USE (LIKE AN
APPLICATION)

RODB
Data
Current
values
Attribute
data

RODB
Manager

RODB
LINK

OS/Ada RTE

FRONTEND PROCESSOR

ISO NOS

7
6
5
4
3
2
1

FRONTEND PROCESSOR

ISO NOS

7
6
5
4
3
2
1

USER'S HOST PROCESSOR

USER'S BACKEND PROCESSOR

COMMAND & CONTROL HIERACHY

TIER I			
SSCC	Crew	OMGA	POIC
GROUND CONTROLLER	OMA		PAYLOAD CONTROLLER

Tier I

SYSTEM MANAGERS

- FMS Manager
- ECLSS Manager
- EVAS Manager
- GN&C Manager
- C&T Manager
- TCS Manager
- DMS Manager
- EPS Manager

ELEMENT MANAGERS

- Prop. Manager
- FTS Manager
- MSS Manager
- APAE Manager
- APM Manager
- JEM Manager
- Node Manager
- US Log Manager
- US Hab Manager
- US Lab Manager

Tier II

Tier III Subsystem Control

Tier III Element Sys. & Equipment Control

Tier III Payload Control

Tier III

FREEDOM

Johnson Space Center

35

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Data Management System

Invited Presentations

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SPACE STATION FREEDOM

SOFTWARE SUPPORT ENVIRONMENT

JANUARY 17, 1990

SUSAN J. VOIGT
IN-SPACE TECHNOLOGY OFFICE
SPACE STATION FREEDOM OFFICE
NASA LANGLEY RESEARCH CENTER

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CONTENTS

This presentation discusses the Space Station Freedom Software Support Environment. After a brief overview of the SSE, the implementation approach and the current and planned functionality are described. The implications and future potential of this common environment for software development and sustaining engineering are also discussed.

40

CONTENTS

o **OVERVIEW OF SSE**

    - WHAT IS THE SSE?

    - WHY IS IT NEEDED?

    - WHO ARE THE USERS?

o **IMPLEMENTATION APPROACH**

    - SCHEDULE

    - ARCHITECTURE

o **SSE FUNCTIONALITY**

o **IMPLICATIONS AND FUTURE POTENTIAL**

WHAT IS THE SSE?

The Software Support Environment (SSE) is a common software environment for all developers of Space Station Freedom Program (SSFP) "operational software". It consists of software tools, procedures, standards, hardware specifications, and user support services including continuing maintenance and upgrade of the SSE, user help desks, training material and documentation.

The SSE System is an environment consisting of computer hardware, communications networks, the SSE and other elements forming an integrated support system for SSFP software developers.

The SSE provides a common set of tools and methods across all the SSFP facilities involved in software life cycle management, including the Software Production Facilities (SPFs) at the four Work Package Centers and Kennedy Space Center, the SSFP integration facilities (to be established) and the SSE Development Facility (SSEDF).

"Operational software" is currently defined by the SSFP as ALL flight and ground software that either   1) interfaces with on-orbit elements in real time, or 2) is critical to the mission, such as all control center, test and certification software including associated models and simulations, or 3) SSE software.

WHAT IS THE SSE?

o   SSE PROVIDES THE COMMON ENVIRONMENT TO BE USED FOR THE LIFE CYCLE MANAGEMENT OF ALL SSFP OPERATIONAL SOFTWARE.

o   SSE IS A COLLECTION OF:

- TOOLS (SOFTWARE)

- RULES (POLICIES, STANDARDS, PROCEDURES, SOFTWARE PRODUCTION HARDWARE SPECS)

- SERVICES (DELIVERY OF OI'S, USER SUPPORT, TRAINING, DOCUMENTATION)

o   THE SSE SUPPORTS ALL SSFP FACILITIES INVOLVED IN SOFTWARE LIFE CYCLE MANAGEMENT. THESE FACILITIES INCLUDE:

- WORK PACKAGE AND KSC SOFTWARE PRODUCTION FACILITIES

- SSFP INTEGRATION FACILITIES

- THE SSE DEVELOPMENT FACILITY

SSE Supports Program Standards

Since the SSE is the common environment for all SSFP software developers, it provides the mechanisms to enforce program-wide software policies and standards. High-level SSFP software policies are set forth in the Level A Software Management Policies, dated November 11, 1986. Elaboration and expansion on these policies are provided in the Level II Software Policies Document currently in under final review prior to becoming a formally baselined Program document. The SSE will be used to support and enforce use of these policies and standards. Current standards include Ada as the standard programming language, a Common User Interface (CUI) definition, standard content formats for software documentation, and a common software verification approach.

SSE SUPPORTS PROGRAM STANDARDS

THE SSE SUPPORTS AND PROVIDES MECHANISMS
TO ENFORCE PROGRAM-WIDE SOFTWARE POLICIES
AND STANDARDS, SUCH AS

- STANDARD PROGRAMMING LANGUAGE (ADA)

- COMMON USER INTERFACE STANDARDS

- SOFTWARE DOCUMENTATION STANDARDS

- COMMON SOFTWARE VERIFICATION APPROACH

SSE System Context

The SSE System consists of a collection of SSE System Elements in a wide area network (WAN). Each SSE System Element consists of a host platform and a collection of workstations running the SSE software. Each element has several external interfaces which may include SSFP operational facilities, Data Management System (DMS) simulation facilities and ground systems, SSE users (connected either directly or through a communications network), TMIS (the Program Technical and Management Information System) and other software production facilities.

46

SSE SYSTEM CONTEXT

External

SSE System

SSFP Operational Facilities

DMS Kit and Ground System

Other External Entities

SSE User

TMIS

Non-SSE Software Production Facilities

WAN SW

WAN

SSE System Element

SSE

SSE System Element

Platform (Host/Work-station)

SSE

SSE System Element

SSE (Other SSE Instances)

SSE System Element

SSE
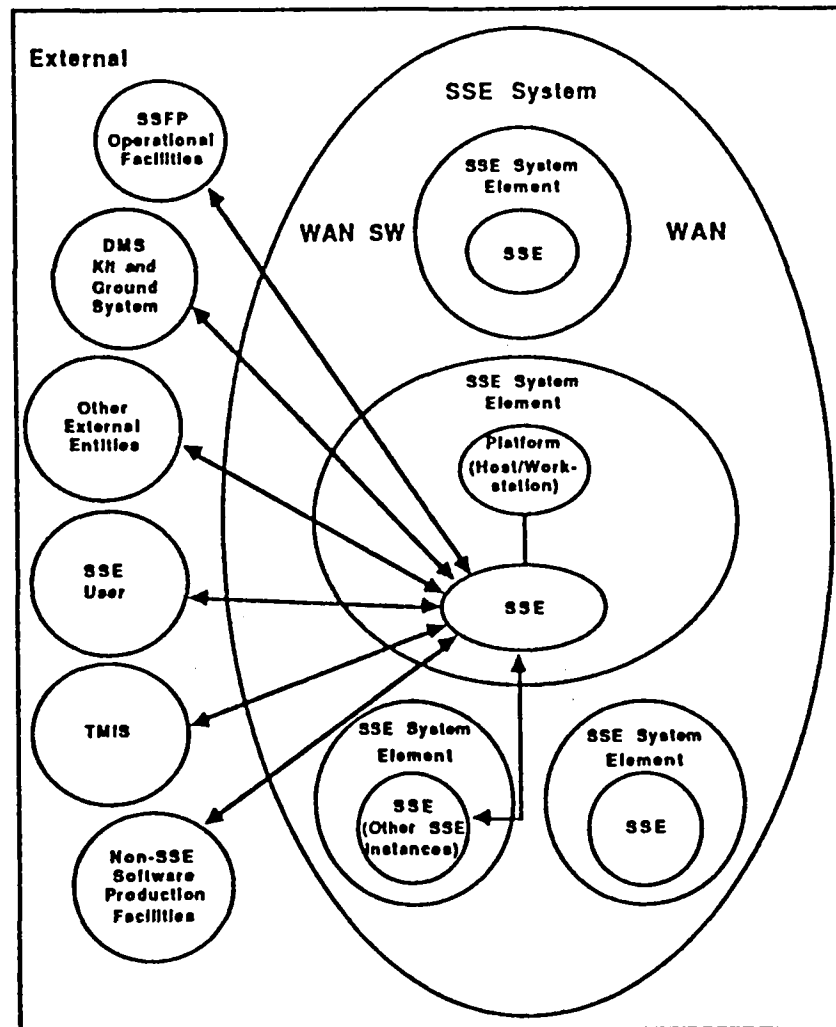
SSE Hosts and Workstations

Two computer systems are currently supported as SSE host computer architectures: Architecture A is the DEC VAX family with VMS operating system and Architecture B is the larger IBM mainframes with VM. The SSE Development Facility has one of each: a DEC VAX 8820 and an IBM 3090.

There are three workstation types currently approved as SSE workstations: IBM PC/AT Compatible (PS/2 Model 60 running DOS and AT compatible personal computers), Apollo DN 3000 running the DOMAIN operating system, and Macintosh II workstation with Finder as the operating system. Currently, consideration is being given to adding the IBM PS/2 Model 80 as another workstation since the software tools available for this and the Apollo are very similar.

48

SSE HOSTS AND WORKSTATIONS

o **SSE HOST COMPUTER ARCHITECTURES AT DF.**

- DEC VAX 8820 WITH VMS OPERATING SYSTEM

- IBM 3090 WITH VM

o **SSE WORKSTATION TYPES.**

- IBM PS / 2 MODEL 60 AND AT COMPATIBLES

- APOLLO DN 3000

- MACINTOSH II

o **ADDITIONAL WORKSTATION, IBM PS / 2 MODEL 80 (80386), UNDER CONSIDERATION.**

Why does SSF need the SSE?

Software is a high risk area for the Space Station Freedom Program in terms of both safety and cost. The quantity of software developed for this program is expected to far exceed that required for previous space programs including the Shuttle Orbiter. Since there are so many different organizations developing software for the SSFP and they are distributed geographically as well, the potential for problems in the integration and testing phase of the development can be alleviated through the use of common tools and standards provided by the SSE.

Through the common environment used by developers of SSFP software, the life cycle costs can be contained in both the development phase by reducing duplicative efforts and especially in the sustaining engineering phase, when the wide use of a common environment will provide a greater base of skilled support personnel.

The SSE will also provide the means to quickly disseminate improved software tools and to increase software quality as technology improvements emerge.

WHY DOES SPACE STATION FREEDOM NEED THE SSE?

o SOFTWARE IS HIGH RISK FOR THE SSFP IN TERMS OF BOTH SAFETY AND COST.

  - LARGE AMOUNT OF SOFTWARE TO BE DEVELOPED.

  - INTEGRATION AND TESTING ARE MAJOR ISSUES.

o SSE PROVIDES A MEANS TO CONTROL SSFP SOFTWARE LIFE CYCLE COSTS.

  - A SINGLE COMMON IMPLEMENTATION APPROACH.

  - A CONSOLIDATION OF SKILLS FOR SUSTAINING ENGINEERING.

o SSE PROVIDES THE MEANS TO CONTROL SSFP SOFTWARE QUALITY THROUGH COMMON PROGRAM-WIDE STANDARDS AND TOOLS.

51

Who are the SSE Users?

The SSE user community consists of all persons involved in the life cycle management of SSFP software. This includes software project managers, requirements analysts, software designers, software developers, testers, quality managers, and software configuration control managers. Most of the users will be Work Package contractors. Other SSE users will come from NASA SSFP organizations, Kennedy Space Center and ground support contractors, Space Station Freedom users, and international partners in the SSFP.

The Software Support Environment User's Working Group (SSEUWG) provides the forum for SSE user information exchange and input to the SSE Project. The SSEUWG has representatives from the NASA Centers and organizations involved in the SSFP, the Work Package contractors, the international partners, and potential SSF customers. Meetings are held approximately quarterly. For more information, contact the SSEUWG Chair, Susan Voigt at NASA Langley.

WHO ARE THE SSE USERS?

o SSE USER COMMUNITY ARE DEVELOPERS, TESTERS AND CONFIGURATION MANAGERS OF SSFP SOFTWARE.

o MAJORITY OF USERS ARE WORK PACKAGE CONTRACTORS.

o OTHER SSE USERS WILL INCLUDE:

   - NASA SSFP ORGANIZATIONS

   - KSC AND NON-PRIME CONTRACTORS

   - SPACE STATION FREEDOM USERS

   - INTERNATIONAL PARTNERS (STANDARD)

o SSEUWG IS THE USER FORUM FOR USER INFORMATION EXCHANGE AND INPUT TO THE SSE PROJECT.

SSE Implementation Approach

The SSE is being developed by Lockheed Missiles and Space Company, Inc. (LMSC) under contract to NASA. The development team is located in Houston, TX near the NASA Johnson Space Center. Subcontractors with LMSC are PRC, SAIC and Ford Aerospace. The six-year contract started on July 10, 1987.

The SSE is being developed incrementally. The first SSE system was delivered to the Government, called the Interim SSE, on September 10, 1987. Operational Increments (OIs) have been delivered periodically to increase the functionality of the SSE. The SSEDF has been recently upgraded to OI 3.2. This system will be delivered to the user Software Production Facilities (SPFs) beginning in mid-February. Future OIs are planned for release about every 5 months.

SSE IMPLEMENTATION APPROACH

o   SINGLE CONTRACTOR FOR SSE DEVELOPMENT.

o   CONTACT AWARDED TO LOCKHEED MISSILES AND SPACE COMPANY, INC., HOUSTON, TX.

-   CONTRACT START DATE (CSD) - JULY 10, 1987.

o   INCREMENTAL DEVELOPMENT.

-   INTERIM SSE SYSTEM (OPERATIONAL INCREMENT 1.0) DELIVERED SEPTEMBER 10, 1987.

-   CURRENTLY SSE SYSTEM AT OI 3.2.
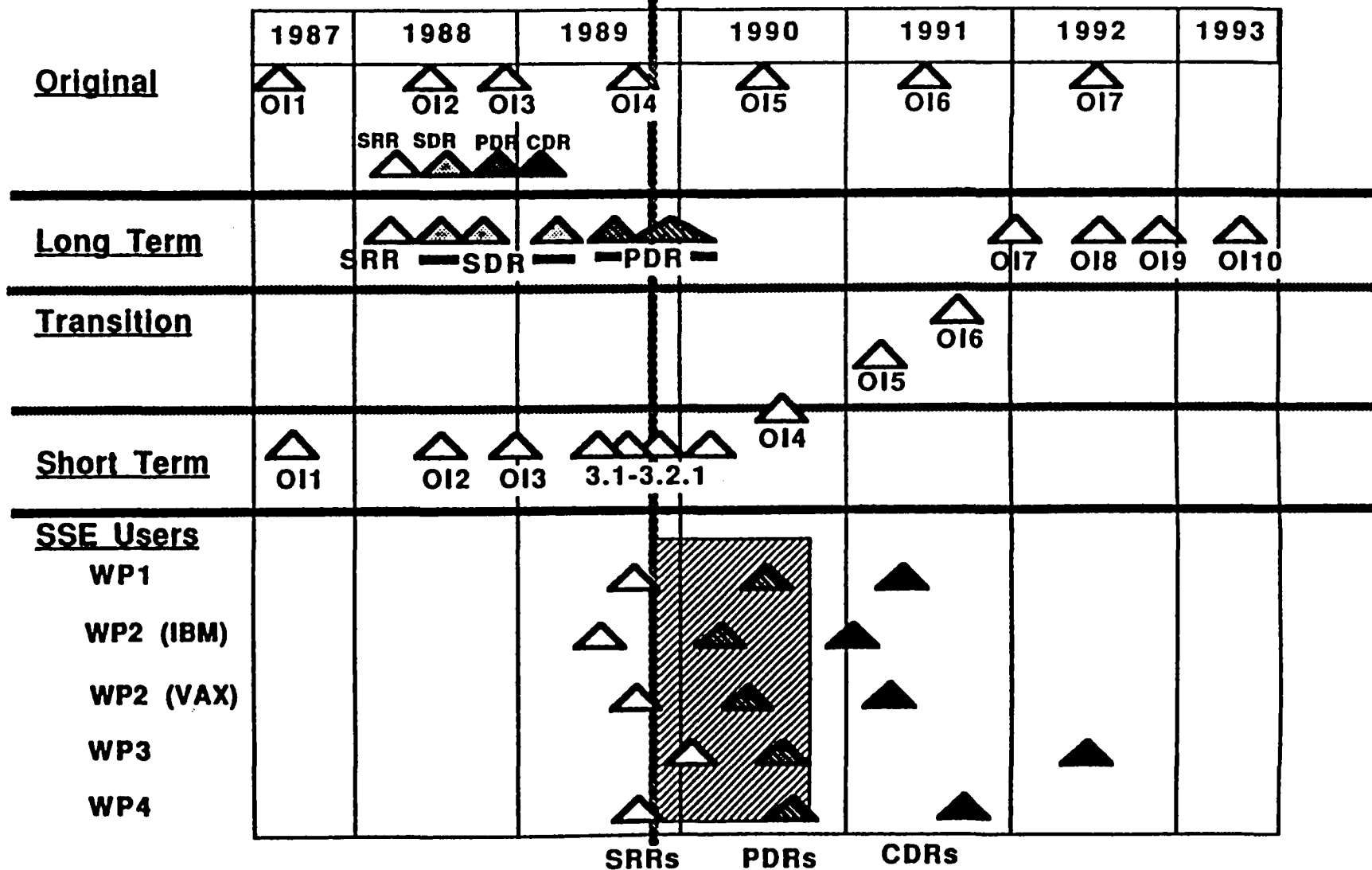
-   FUTURE OI'S TO BE DELIVERED EVERY 5 MONTHS.

Status and Challenges

The SSE Project Schedule has undergone some replanning in the last year. The original plan called for completion of the SDR in mid 1988, but achieving a requirements specification that was satisfactory to the user community and the SSFP took considerably longer than expected Subsequent review points have also slipped. The original approach called for a replacement system at OI 4.0, but under the revised plan, the interim SSE system is gradually being refined and will transition to the new SSE architecture by OI 7.0. Meanwhile, the five SPFs have been installed and are operational at Work Package contractor sites. These contractors have software reviews (PDRs and CDRs) that require support from the SSE, and these are also depicted on the schedule.

STATUS AND CHALLENGES

SSE PROJECT SCHEDULE

	1987	1988	1989	1990	1991	1992	1993
Original	OI1	OI2 OI3	OI4	OI5	OI6	OI7	
		SRR SDR PDR CDR					
Long Term		SRR ▬ SDR ▬	▬ PDR ▬		OI7	OI8 OI9	OI10
Transition					OI5 OI6		
Short Term	OI1	OI2 OI3	3.1-3.2.1	OI4			
SSE Users							
WP1							
WP2 (IBM)							
WP2 (VAX)							
WP3							
WP4							

SRRs   PDRs   CDRs

SSE Implementation Status

Software Production Facilities (SPFs) are installed at five Work Package contractor sites: Work Package 1 - Boeing, Huntsville, AL; Work Package 2 - McDonnell Douglas, Huntington Beach, CA and IBM, Houston, TX; Work Package 3 - General Electric, King of Prussia, PA; and Work Package 4 - Rocketdyne, Canoga Park, CA. An additional SPF is planned for support at Kennedy Space Center at Harris Corporation, Rockledge, FL.

The SSE Operational Increment (version) 3.1 is installed on the five operational SPFs. OI 3.2 has already been installed at the SSEDF and will be installed in the SPFs beginning in February. The next OI will be OI 4.0, ready for installation in the fall 1990.

SSE IMPLEMENTATION STATUS

o SOFTWARE PRODUCTION FACILITIES AT 5 SSFP CONTRACTOR
   SITES.

    - ROCKETDYNE - CANOGA PARK, CA.

    - McDONNELL DOUGLAS - HUNTINGTON BEACH, CA.

    - BOEING - HUNTSVILLE, AL.

    - IBM - HOUSTON, TX.

    - GENERAL ELECTRIC - KING OF PRUSSIA, PA.

o SSE SOFTWARE PRODUCTION FACILITY PLANNED FOR
   HARRIS CORPORATION, ROCKLEDGE, FL.

o SSE CAPABILITIES IN PLACE.

    - OI 3.1 IS INSTALLED AT THE 5 SPFs.

    - OI 3.2 INSTALLATION WILL BEGIN AT SPFs IN FEBRUARY 1990.

    - OI 4.0 SCHEDULED FOR FALL 1990.

SSE Architecture

The architecture for the eventual SSE is a layered one, with very well defined interfaces between the layers, so that it can evolve over the 30 year life time of the Space Station Freedom. The Common User Interface layer is the external view the user will have. It will be based on industry standards such as X-windows and OSF/MOTIF. the software tools that support the users are called "environment applications" and these may be commercial off the shelf (COTS) products or specially tailored tools and procedures. Below that layer is the Process/Object Management layer which contains the mechanisms to provide life cycle support for both software development processes and the objects (specs, designs, code, test procedures, test data, etc.). The lowest layer is the host and workstation platform operating systems on which the SSE system must run.

SSE ARCHITECTURAL MODEL (LONG-TERM)

SSE
Users

User-Visible Views

SSE
(Integrated Life-Cycle Support for Software)

Common User Interface Services
(Standard, Tailorable, User Interface Services)

Environment Applications
(Configurable Tools, Rules, Procedures)

Process/Object Management
(Life-Cycle Support for Processes and Objects)

Platform
(Hosts, Workstations, Networks)

Performance-Driven Interfaces

Logical Layers

≈ SSE Standard Interface

━━━ = No Interface Across Line

61

The SSE Project replan includes a transition phase during which the SSE will evolve from the current collection of proprietary and COTS software to a target architecture which contains the four layers of the final architecture, but also permits "non-conforming environmental applications" which are COTS that require direct user interface and cannot be handled through the common user interface services. The SSE Architectural Design Document (contract document requirements list item number 58) describes the architecture in more detail.

SSE TRANSITION PLAN

SSE SOFTWARE ARCHITECTURE
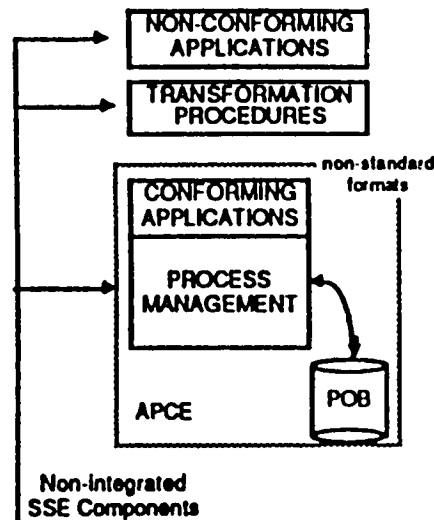
CURRENT SSE   SSE TARGET ARCHITECTURE
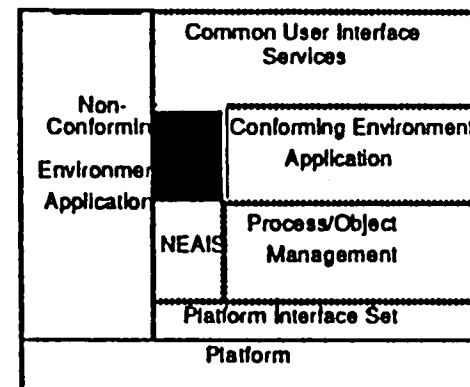
o **DURING THE TRANSITION PERIOD SPANNING FROM OI 4 THROUGH OI 6 THE CURRENT SSE WILL EVOLVE FROM A COLLECTION OF PROPRIETARY AND COTS SOFTWARE CAPABILITIES TO THE NEAR TERM GOAL ARCHITECTURE DEFINED IN THE SSE ARCHITECTURAL DESIGN DOCUMENT (DRLI 58)**

This is a detail from the SSE Architectural Design document showing the elements of SSE OI 5.0, with several non-conforming tools, many of which reside on the SSE workstations, and some conforming applications/tools which are being developed specifically by the SSE Project. Major elements of the Process Object Manager will also be complete by OI 5.0.

CUBE MODEL OF THE SSE OI 5.0
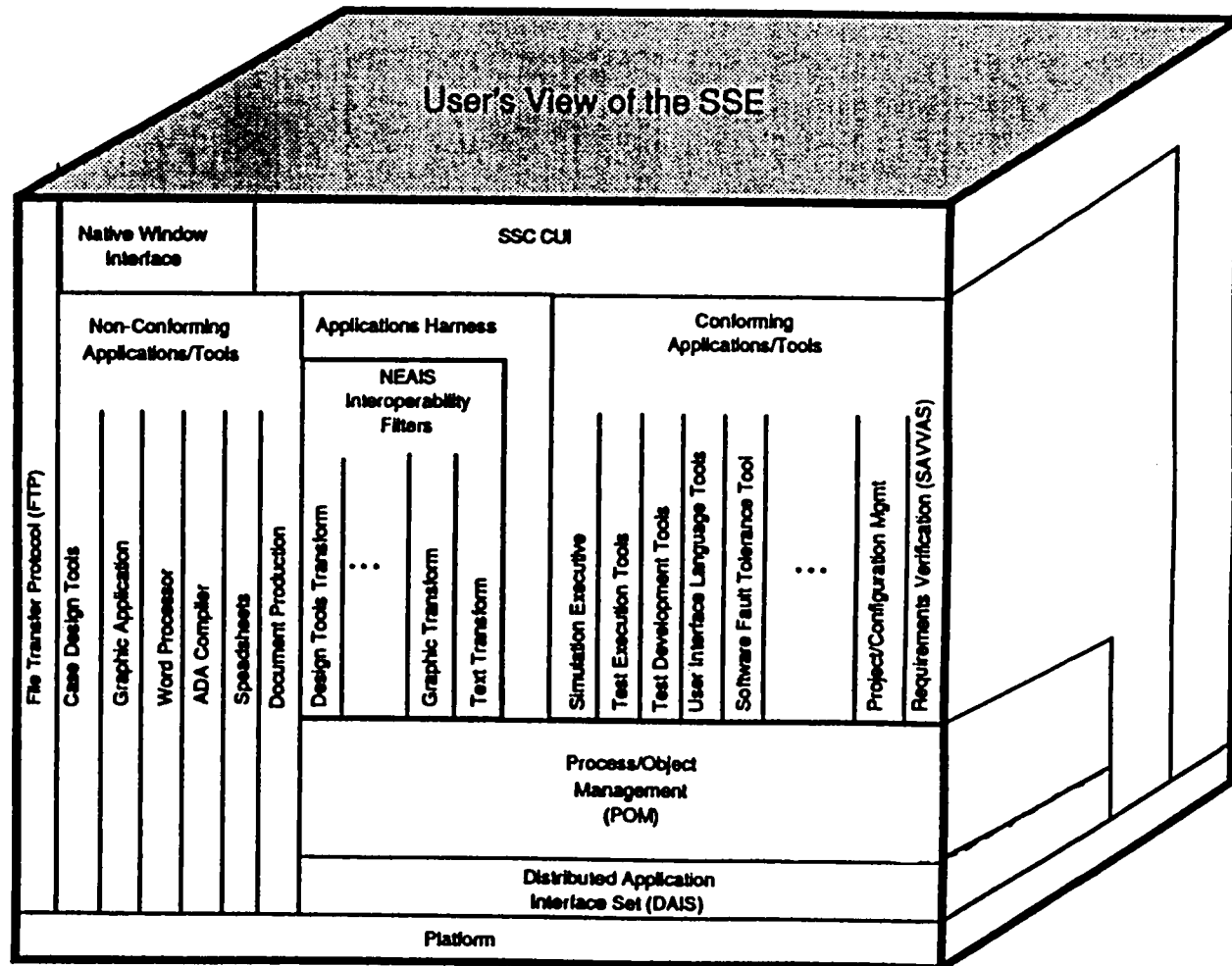
SSE Functionality

The SSE provides support for software development in Ada. If the SSFP authorizes additional standard languages, the SSE will be expanded to support them as well.

The SSE Ruleset provides the software standards, guidelines, and procedures to support software acquisition, integration, verification and maintenance. It provides support to enforce the software policies and standards established by the SSFP.

The SSE Toolset provides the tools necessary to acquire, integrate and deliver SSFP operational software during all life cycle phases. The tools encompass the following functional areas: SSE process management; software management support; software production; flight software integration, test and verification; data reconfiguration, training, and library (object) management. The SSE also provides services such as delivery and configuration management of the SSE software itself, user support, training, and documentation.

SSE FUNCTIONALITY

o SSE SUPPORTS SOFTWARE DEVELOPED IN ADA.

o SSE RULESET PROVIDES SOFTWARE STANDARDS, GUIDELINES AND PROCEDURES.

o SSE TOOLSET PROVIDES ALL SOFTWARE TOOLS NECESSARY TO ACQUIRE, INTEGRATE AND DELIVER SSFP OPERATIONAL SOFTWARE. SSE TOOLS ENCOMPASS THE FOLLOWING FUNCTIONAL AREAS:

- SSE PROCESS MANAGEMENT
- SOFTWARE MANAGEMENT SUPPORT
- SOFTWARE PRODUCTION
- FLIGHT SOFTWARE INTEGRATION, TEST AND VERIFICATION
- DATA RECONFIGURATION
- TRAINING
- LIBRARY (OBJECT) MANAGEMENT

o SSE SERVICES ENABLE SSE USAGE FOR SSFP.

SSE Requirements Specification

The SSE functional and detailed requirements have been documented in the project documents DRLI 16 and 72. This chart indicates the various categories of requirements and how they are organized in the SSE Requirements Specification Document (DRLI 72) Some requirements specifically support user activities and others are computer process support requirements.

SSE REQUIREMENTS SPECIFICATION

SSE REQUIREMENTS ORGANIZATION

SECTIONS 4.2 - 4.7
(NECESSARY FOR OPERATIONAL S/W DEVELOPMENT)

SECTION 4.8
(ANCILLARY
FUNCTIONS)

SUPPORT
USER
REQUIREMENTS

- PROJECT MANAGEMENT
- CONFIGURATION MANAGEMENT
- SR&QA
- OFFICE AUTOMATION
- DOCUMENTATION PROCESSING
- SOFTWARE PRODUCTION
- IT&V
- RECONFIGURATION DATA HANDLING
- MODEL/SIMUATION DEVELOPMENT
- MODEL/SIMULATION EXECUTION
- PROVIDED MODELS
- MODEL/SIMULATION REPOSITORY
- COMPUTER BASED TRAINING
- SYSTEM MANAGEMENT
- REUSE LIBRARY MANAGEMENT
- SSE SUBSET MANAGEMENT

SECTION 4.1

COMPUTER
PROCESS
SUPPORT
MANAGEMENT
REQUIREMENTS

OPERATING SYSTEM INTERFACE
DATA BASE MANAGEMENT
COMMUNICATIONS
USER INTERFACE
PROCESS EXECUTIVE

SSE Project Overview/Functional Capabilities

The allocation of the requirements to the SSE architecture is depicted in this diagram which shows various elements in the SSE design and the categories of tools or functional areas contained in each. The SSE architectural design has evolved so that the terms "Framework" and "Test and Tools Harness" have been replaced. The process management element is now part of the Process/Object Management layer, and the tools are called environment applications. The functional capability of the harness is embodied in the interface between the common user interface and the environment applications layers.

70

SSE Functional Capabilities

							SSE Management
Framework	Process Management Element				Software Management Support Element		
	Executive - SW Integ. &Test Mgmt - Test & Integ Control - Interface Between Applications And Comm Element - SR & QA Enforcement Control - Project Management Initiation and Control	DBM	Config. Control - Release and Delivery Control		Configuration Management		- Library Mgmt. - Resource Requirements Gathering - Performance Monitoring

Test and Tools Harness

Tools	SW Mgmt Support Element	SW Production Element	Data Reconfiguration Element	Modeling, Sim, & SW Checkout Element	Training Element	Other	- Production Facility Generation
	- Document Processing - Office Automation - SR & QA - Project Mgmt. (Budgeting, Scheduling, & Lessons Learned	- Requirements Definition (Document Testing) - Preliminary Design, Detailed Design & Implementation - TCI Verification, Simulation, Standards Compliance - Static & Dynamic Analyzers - Software Initiation	- Data Processing	- Test Component Generator - Test Data Analyzer - Internal Standards Compliance - Simulators	- Development of Training Materials		- Project Generation - SSE System Management - Non-SSE Input - Qualification

System	Process Management Element						
				Comms			

71

Implications and Future Potential

In the near term, the SSE Project will need to focus its resources on providing support to the most critical needs of the Space Station Freedom development teams. With each OI, the SSE will transition more towards the long term architecture. As the Process Object manager evolves, a more object-oriented approach will be enabled, and the layered architecture will have better defined interfaces. The well-defined interface layers will permit changes within any of the layers without a cascading impact on the entire system.

The primary benefits of the SSE will probably not be evident until the Space Station Freedom is in orbit and the program reaches a sustaining engineering and growth status. Then the disciplined software approach enabled by the SSE will make the continued operation and expansion of the software much more tractable.

The layered architecture of the SSE also provides great potential for migrating new software technologies to the SSE, such as improved requirements analysis tools, expert system design aids, elaborate reuse library support, and formal verification.

IMPLICATIONS AND FUTURE POTENTIAL

o **NEAR TERM - SSE PROJECT WILL FOCUS ON SUPPORTING WORK PACKAGE CONTRACTOR DEVELOPMENT EFFORTS**

o **EVOLUTION TO SSE LAYERED ARCHITECTURE PROVIDES GOOD BASIS FOR CONTINUED GROWTH AND IMPROVEMENT OF SSE CAPABILITIES.**

o **SUSTAINING ENGINEERING OF SSFP SOFTWARE USING THE SSE RULES AND TOOLS WILL BE MORE TRACTABLE AND COST EFFECTIVE THAN UNDISCIPLINED DEVELOPMENT AND SUPPORT.**

o **NEW SOFTWARE TECHNOLOGIES CAN MIGRATE TO THE SSE, SUCH AS IMPROVED REQUIREMENTS ANALYSIS TOOLS, EXPERT SYSTEM DESIGN AIDS, ELABORATE REUSE LIBRARY SUPPORT AND FORMAL VERIFICATION.**

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VALIDATED FAULT TOLERANT ARCHITECTURES
FOR SPACE STATION

C
S
D
L

by

Jaynarayan H. Lala

Presented at

The Workshop on Technology

for

Space Station Evolution

Dallas--Fort Worth, Texas

January 17, 1990

The Charles Stark Draper Laboratory, Inc.

Cambridge, Massachusetts 02139

OUTLINE
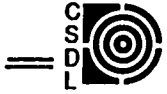
- **Fault Tolerance Approach**
- **Advanced Information Processing System (AIPS)**
- **Fault Tolerant Parallel Processor (FTPP)**
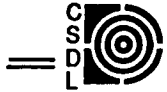
BASELINE DESIGN AND VALIDATION PROCESS

- Baseline processor and network architectures for space station rely on a combination of computer self-tests and diagnostics and additional diagnostics by the crew to:

  - detect and isolate in-orbit failures of computers, networks and their interfaces to sensors and subsystems

  - reconfigure, repair and revalidate the system following each component failure

- Design and validation of distributed fault tolerant architectures is accomplished by extensive testing of ad hoc designs which have been put together using subjective criteria

NEED FOR VALIDATED
FAULT TOLERANT ARCHITECTURES

- **A validated fault tolerant computer system architecture is required that can autonomously:**

  - monitor its own status

  - monitor the status of sensors and subsystems with which it interfaces

  - detect and isolate faults in computers, networks, sensors and subsystems

  - reconfigure the resources in realtime to continue to perform all the critical functions without manual (crew) intervention for reconfiguration and revalidation

- **As Space Station evolves to support advanced missions, its computer system architecture must also extend to support:**

  - mixed redundancy

  - function migration

  - reliable communication between physically distributed computers of different redundancy levels
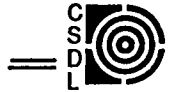
DRAPER APPROACH TO
FAULT TOLERANT COMPUTER DESIGN

- Draper lab has designed fault tolerant computers which possess the following attributes:

  - validatable

  - Byzantine resilient

  - very low fault tolerance overheads

  - fault tolerance and redundancy management are transparent to user

BYZANTINE FAULTS DEFINITION

- **A Byzantine fault is an arbitrary behavior on part of a hardware component, a software module or a logical entity**

- **A particularly malicious manifestation of a byzantine fault is a "lying fault"**

BYZANTINE RESILIENCE - MOTIVATION

Design Example:

- **Highly reliable digital control**

- **10e-9 per hour maximum system loss probability**

- **10e-4 per hour channel failure rate (typical)**

BYZANTINE RESILIENCE - MOTIVATION

Approach 1:

- **Enumerate each possible failure mode and provide a fault tolerance technique for each**

- **Uncovered failure probability must be less than < 10e-5**

Problems:

- **Must demonstrate that fewer than 1 in 100,000 failures can cause loss of control**

- **Difficult validation problem**

- **Difficult reliability analysis problem**

BYZANTINE RESILIENCE - MOTIVATION

Strange failure mode: Failure on A's transmit bus causes B, C, and D to diverge

I'm OK

A's OK

A's Faulty

A's OK

Processor A

Processor B

Processor C

Processor D

"I'm OK"

"*(&(*"

"I'm OK"
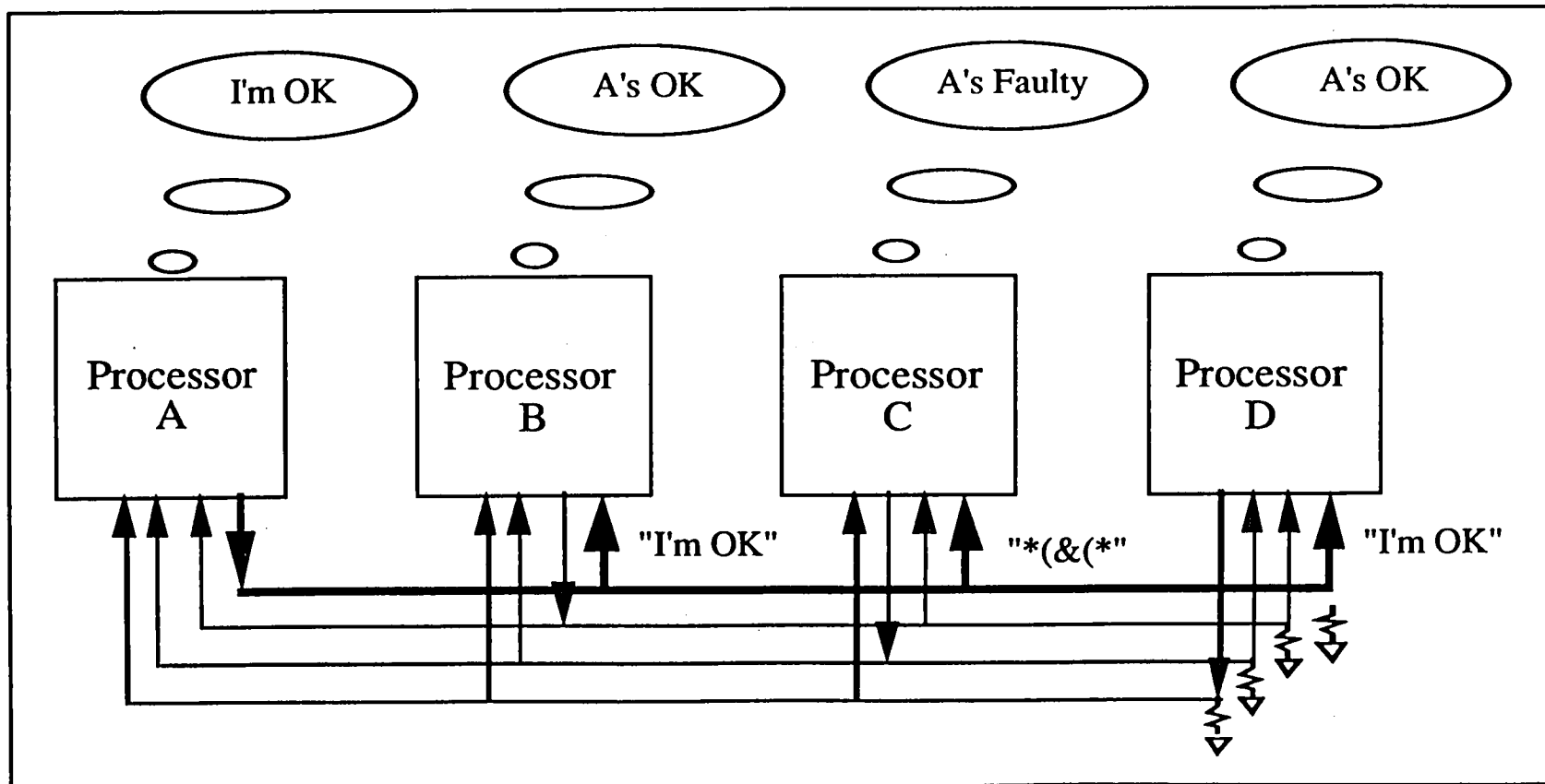
BYZANTINE RESILIENCE - MOTIVATION
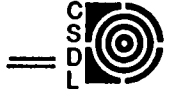
Examples of strange failure modes:

- In-flight failure of YC-14 flight control computer
- Promiscuous network node failure
- FTPP inconsistent vote errors
- FTP power supply-induced error

BYZANTINE RESILIENCE
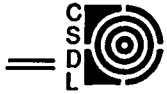
Approach 2:

- Make <u>no</u> guesses about likely failure modes
- Tolerate arbitrary failure behavior:

  "Byzantine Resilience"

Advantages:

- Theoretical requirements for Byzantine Resilience well-known and unambiguous
- Easier validation and analysis problem
- Higher reliability than other approaches

BYZANTINE RESILIENCE - REQUIREMENTS

**Theoretically correct implementation of Byzantine Resilience requires:**

- **Bitwise comparison of results emanating from redundant sites of equivalent state complexity**

- **3f+1 fault containment regions (FCRs)**

- **2f+1 inter-FCR connectivity**

- **f+1 round inter-FCR protocol**
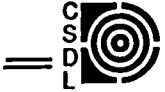
- **FCR synchrony**

BYZANTINE RESILIENCE -REQUIREMENTS

1-Byzantine Resilient processing site:

- **4 identical FCRs**

- **fully connected**

- **2-round interactive consistency protocol**

- **synchronous**

Fault Containment Region

Disjoint Paths
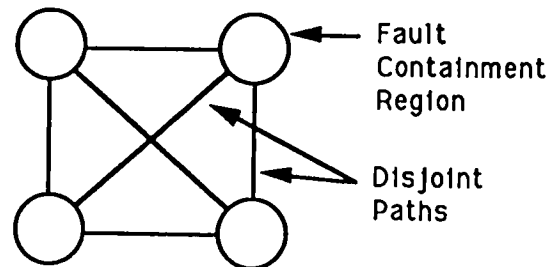
ADVANCED INFORMATION PROCESSING SYSTEM

Objective

Develop an objective knowledgebase and demonstrate system building blocks which will allow achievement of validated fault tolerant distributed computer system architectures for a broad range of advanced aerospace applications.

Accomplishments

Demonstrated major attributes of the AIPS architecture using the engineering model:

- **Validatability**
- **Distributed computation**
- **Mixed redundancy**
- **Fault tolerance (processors, networks, interfaces)**
- **Damage tolerance**
- **Graceful degradation**
- **Expandability**
- **Transparency of fault tolerance to applications programmer**
- **Low fault tolerance overhead**

ADVANCED INFORMATION PROCESSING SYSTEM

C
S
D
L

Accomplishments

Produced an analytical and empirical knowledgebase for the validation of the AIPS <u>architecture and building blocks</u>:

- Architecture design rules and guidelines
- Analytical reliability and availability models
- Analytical performance models
- Empirical reliability data
- Empirical performance data
- Analytical cost models

Completed the distributed engineering model for the demonstration of the AIPS attributes and for test & evaluation; Demonstrated the following buildingn blocks:

- 3 triplex FTPs
- 1 simplex processor
- triplex intercomputer network
- mesh I/O network
- System Services software (85,000 lines of Ada Code)

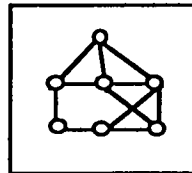# AIPS BUILDING BLOCKS: HARDWARE
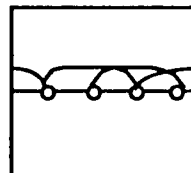
FAULT TOLERANT PROCESSORS
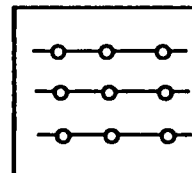
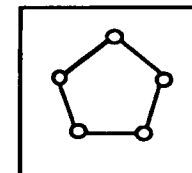Simplex · Duplex Triplex Quadruplex
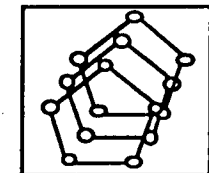
**INTERCONNECTION
NETWORKS**

MESH
BRAIDED
MESH
REDUNDANT
BUSES
RING
REDUNDANT
RINGS

INTERFACES

IOS Input/Output Interfaces

ICIS Inter-Computer Interface Sequencer

AIPS BUILDING BLOCKS: SOFTWARE

LOCAL SYSTEM SERVICES:
  Ada Real Time Operating System
  FTP Redundancy Management
  Local Time Management

INPUT/OUTPUT (I/O) SYSTEM SERVICES:
  I/O User Communications
  I/O Redundancy Management

INTERCOMPUTER (IC) SYSTEM SERVICES:
  Ada Distributed Synchronous
  Communications
  IC User Communications
  IC Redundancy Management

SYSTEM MANAGER:
  Function Allocation & Migration
  System Redundancy Management
  Global Time Management

AIPS ENGINEERING MODEL CONFIGURATION
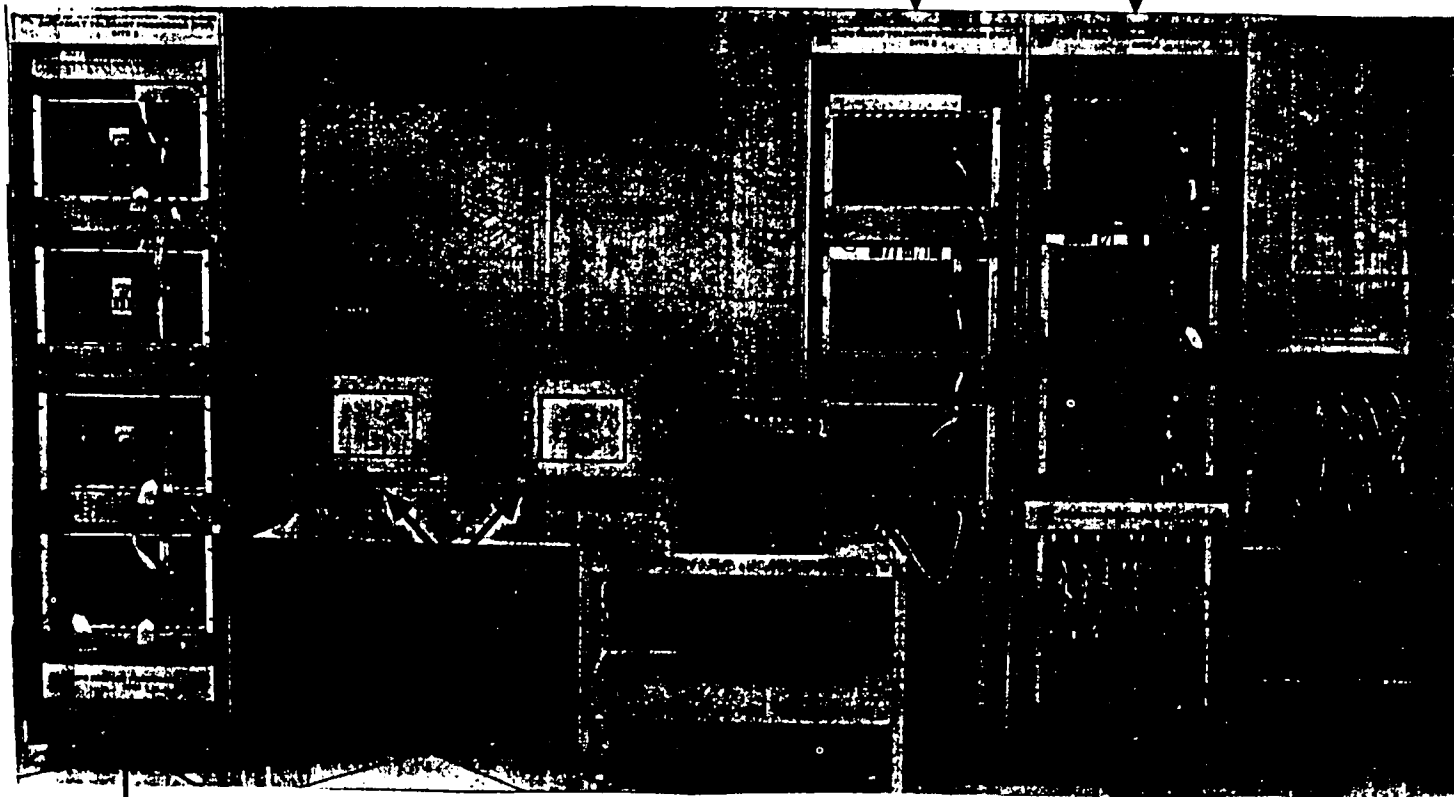
AIPS ENGINEERING MODEL

Triplex FTP
(Site 2)

Triplex FTP
(Site 3)

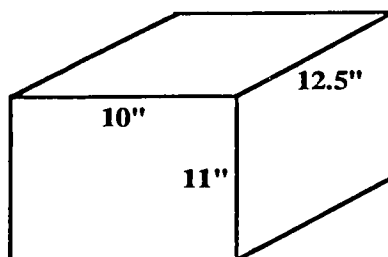Triplex FTP
(Site 4)

Simplex Processor
(Site 1)

Triplex IC Network

TRIPLEX FTP CHARACTERISTICS

AIPS FAULT TOLERANT PROCESSOR

SIZE: 0.8 CUBIT FEET

WEIGHT: 50 lbs

POWER: 42 watts

THROUGHPUT: 20 MIPS

MEMORY: 4 MBYTES

RELIABILITY: $10^6 - 10^7$ hrs MTBCF

PROB. OF FAILURE: 10^{-6} to 10^{-7} per hour

REDUNDANCY: Triplex (Expandable to quad)

FAULT TOLERANCE: Fail-Operational, Fail-Safe

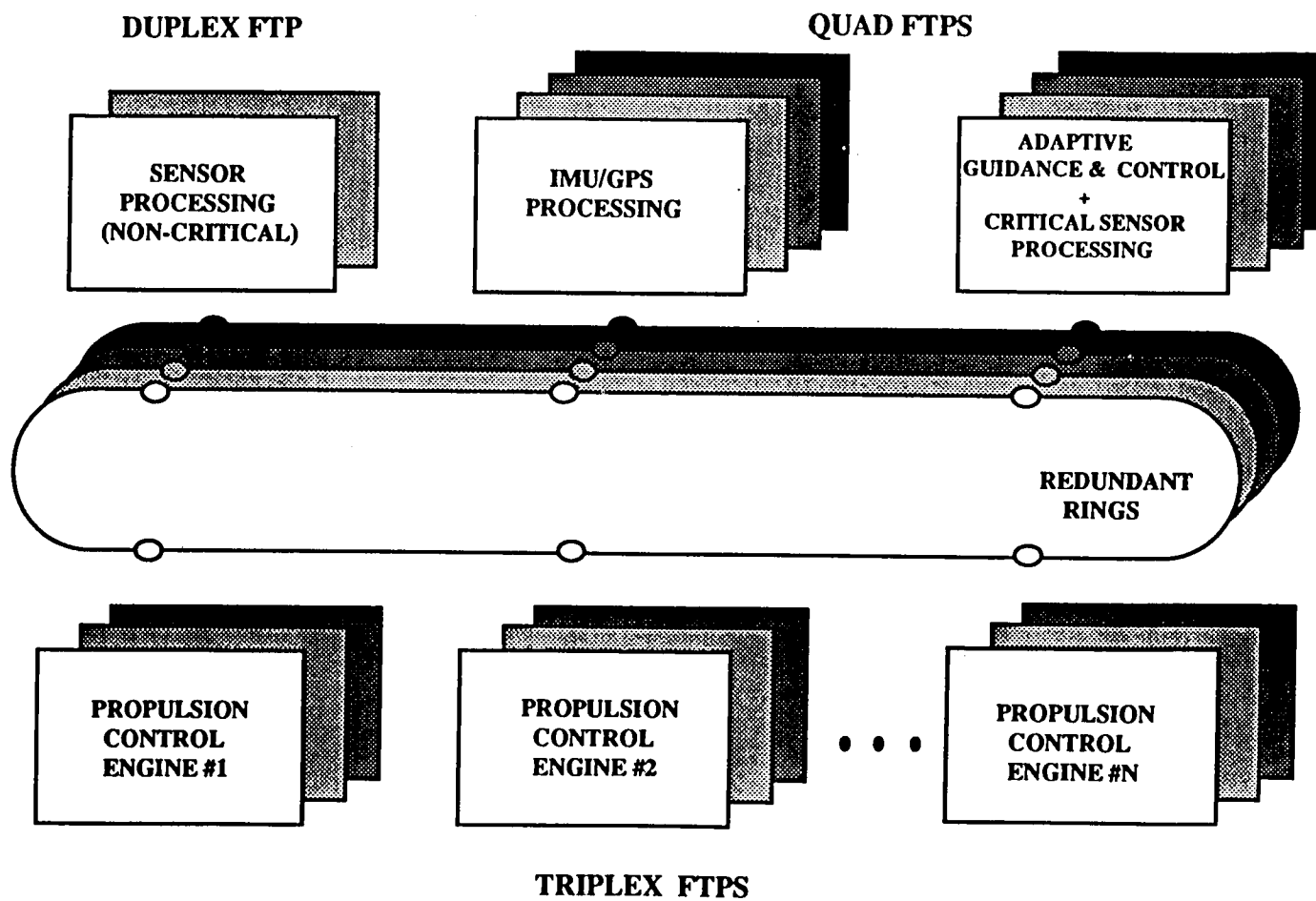**MODULARITY:** Highly Modular

EXPANDABILITY: Network of FTPs

PROGRAMMING LANGUAGE: Ada

ADVANCED LAUNCH SYSTEM AVIONICS BLOCK DIAGRAM

DUPLEX FTP

QUAD FTPS

SENSOR
PROCESSING
(NON-CRITICAL)

IMU/GPS
PROCESSING

ADAPTIVE
GUIDANCE & CONTROL
+
CRITICAL SENSOR
PROCESSING

REDUNDANT
RINGS

PROPULSION
CONTROL
ENGINE #1

PROPULSION
CONTROL
ENGINE #2

• • •

PROPULSION
CONTROL
ENGINE #N

TRIPLEX FTPS

FAULT TOLERANT PARALLEL PROCESSOR OBJECTIVES
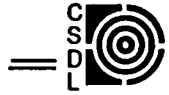
- **Develop concepts applicable to high reliability parallel processing**

- **Demonstrate key concepts via proof of concept**

- **Make FTPP available to NASA/DoD community**

ATTRIBUTES

- **Message-passing parallel computer**

- **Messages serve both intercomputer communication and fault tolerant purposes**

- **Efficient hardware implementation of fault tolerance-specific functions**

ATTRIBUTES (CONT.)
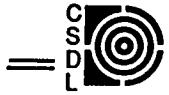
- **Highly reconfigurable**

  - **Trades redundancy for throughput in real time**

  - **Allows variety of redundancy management modes**

- **Supports dissimilar processing sites**

- **Supports off-the-shelf components**

- **Programmable in C, ADA, or Assembler**

FTPP POC CONFIGURATION
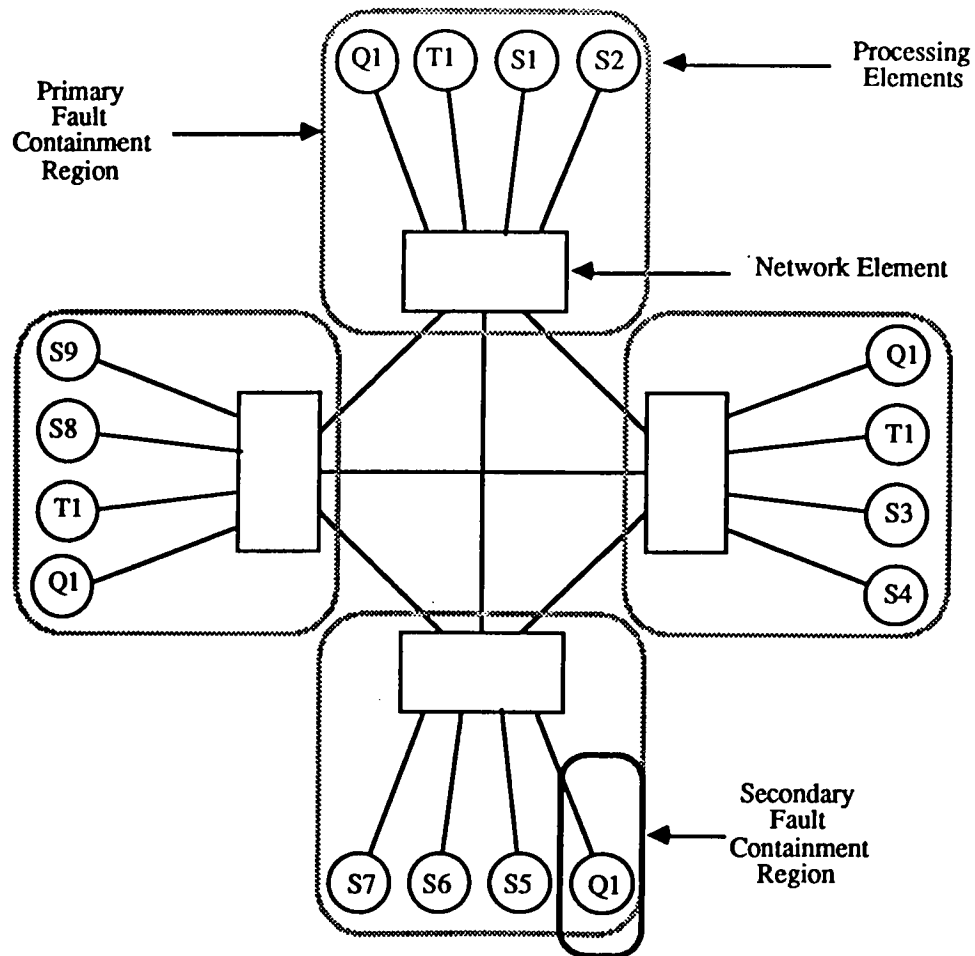
Q1 Quad 1
T1 Triad 1
S1-S9 Simplexes 1-9

192-PE FTPP

FTPP POC

Fault Containment Region

Network Element

Processing Elements
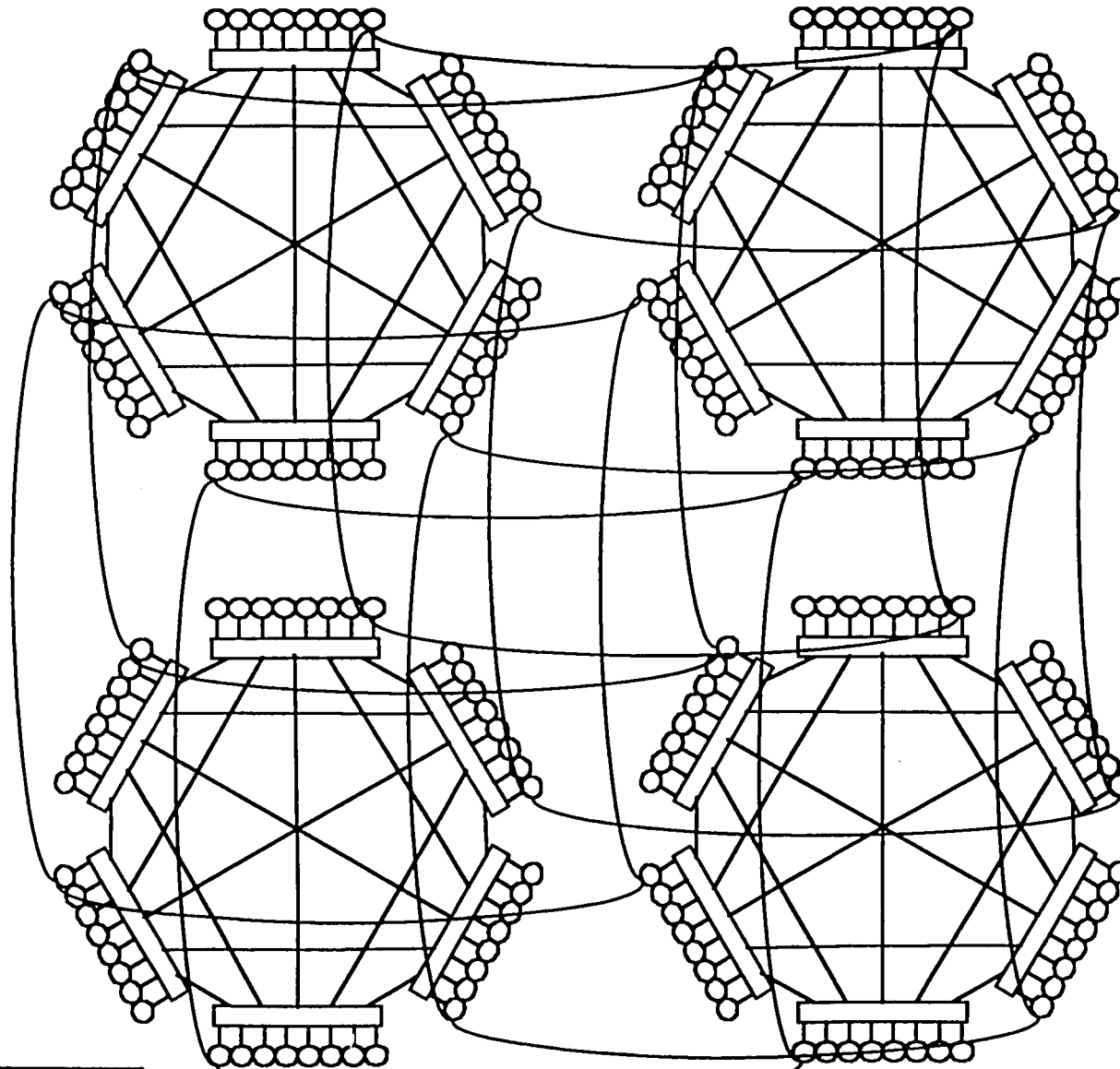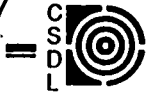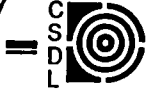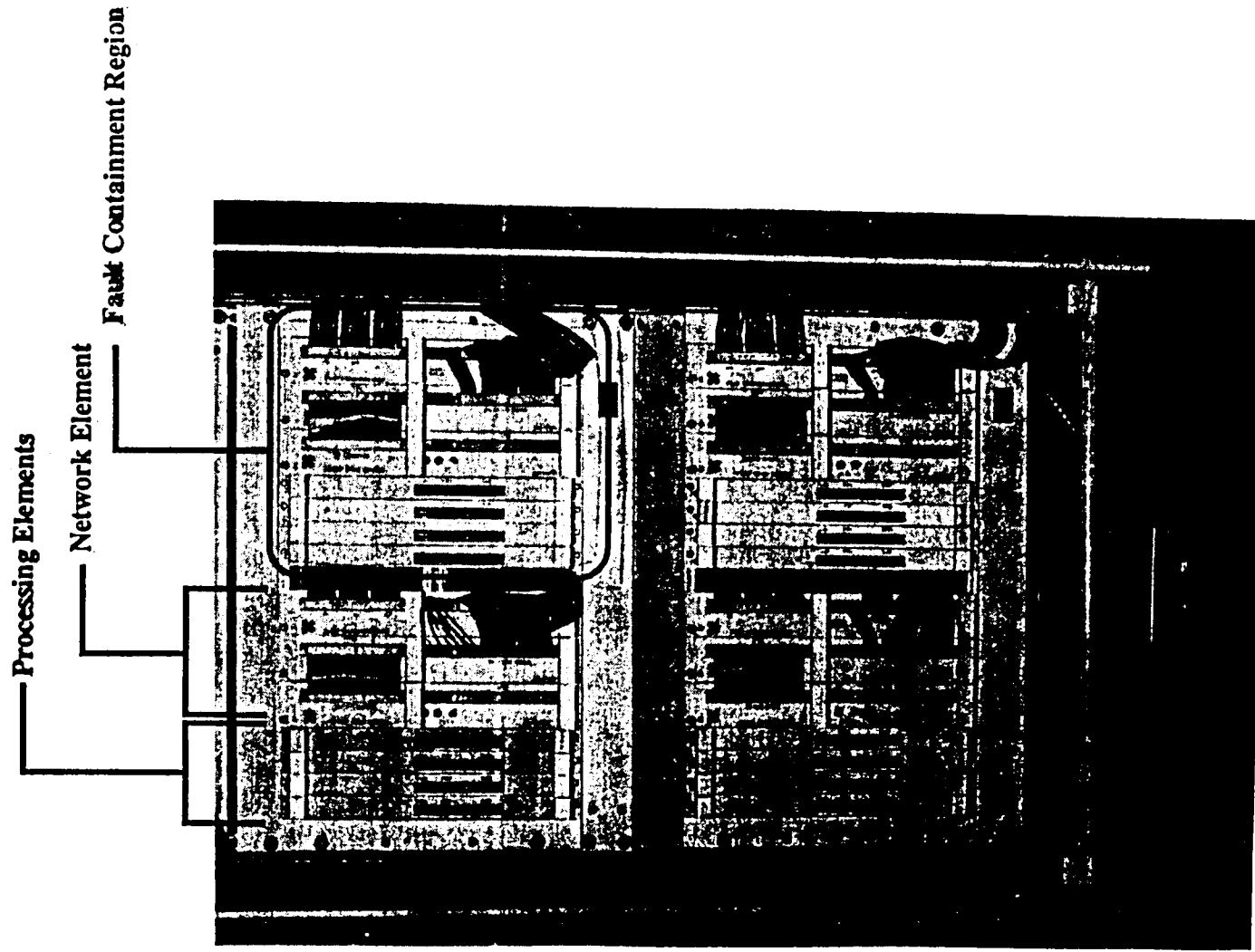
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A FAULT-TOLERANT RISC MICROPROCESSOR FOR SPACECRAFT APPLICATIONS

CONSTANTIN TIMOC

SPACEBORNE INC.

HARRY BENZ

NASA/LaRC

REDUCED INSTRUCTION SET COMPUTER

CONTROL UNIT

```
HARDWIRED
(NOT MICROPROGRAMMED)
```

DATA AND ADDRESS UNIT

ADDRESS ADDER
PC INCREMENTER/MUX
GENERAL REGISTERS (32 x 32)
ALU
SHIFTER
MULTIPLIER/DIVIDER

INTERRUPT UNIT
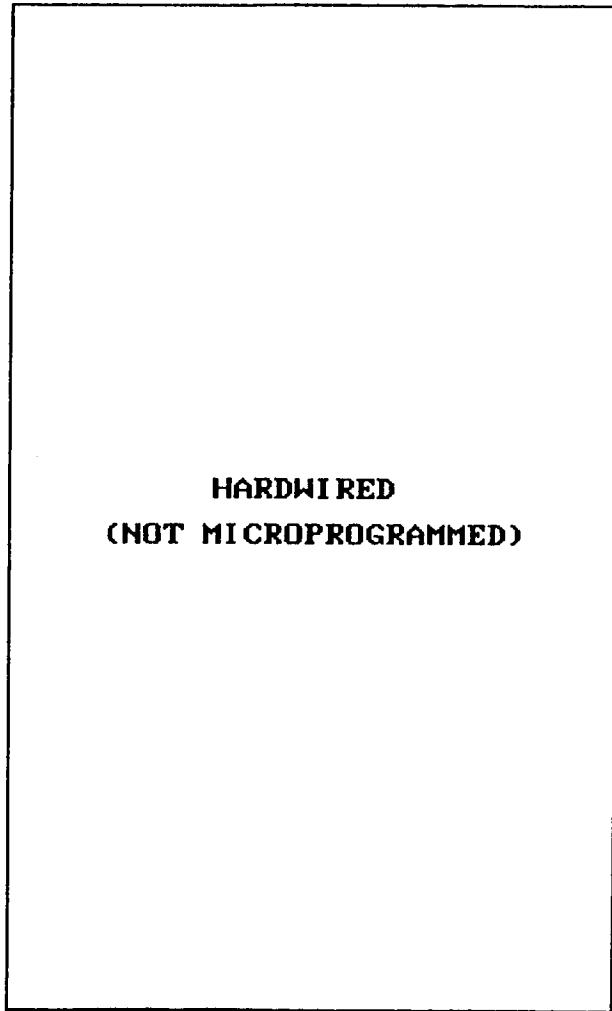
INTERRUPT REGISTERS
PRIORITY INTERRUPT LOGIC
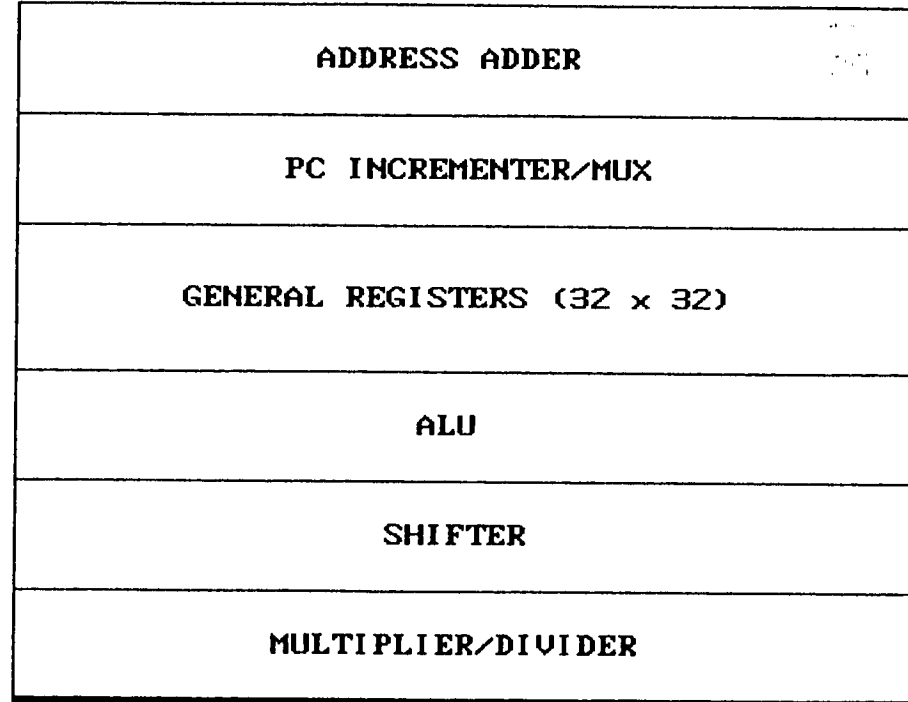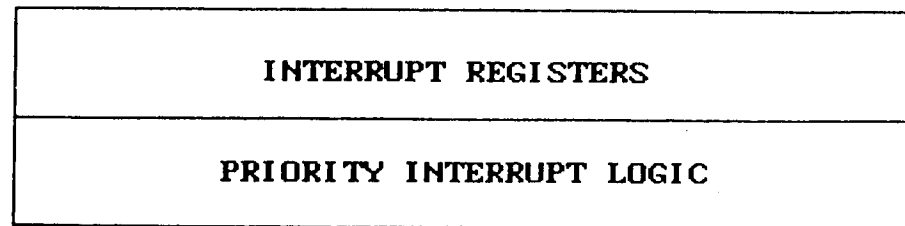
FAULT TOLERANT REGISTERS

GENERAL REGISTERS (32 x 32)	CHECK BITS

DOUBLE-RAIL

ERROR DETECTION AND CORRECTION LOGIC

FAULT TOLERANT ALU

FAULT TOLERANT ALU

DATA A

DATA B

DOUBLE-RAIL

DOUBLE-RAIL

32-BIT ALU

32-BIT ALU

ERROR CORRECTOR

DOUBLE-RAIL

SUM

106

DOUBLE RAIL CMOS LOGIC

F = X0.X1

$\overline{F} = \overline{X0.X1}$

X0

$\overline{X0}$

X1

$\overline{X1}$

CLK
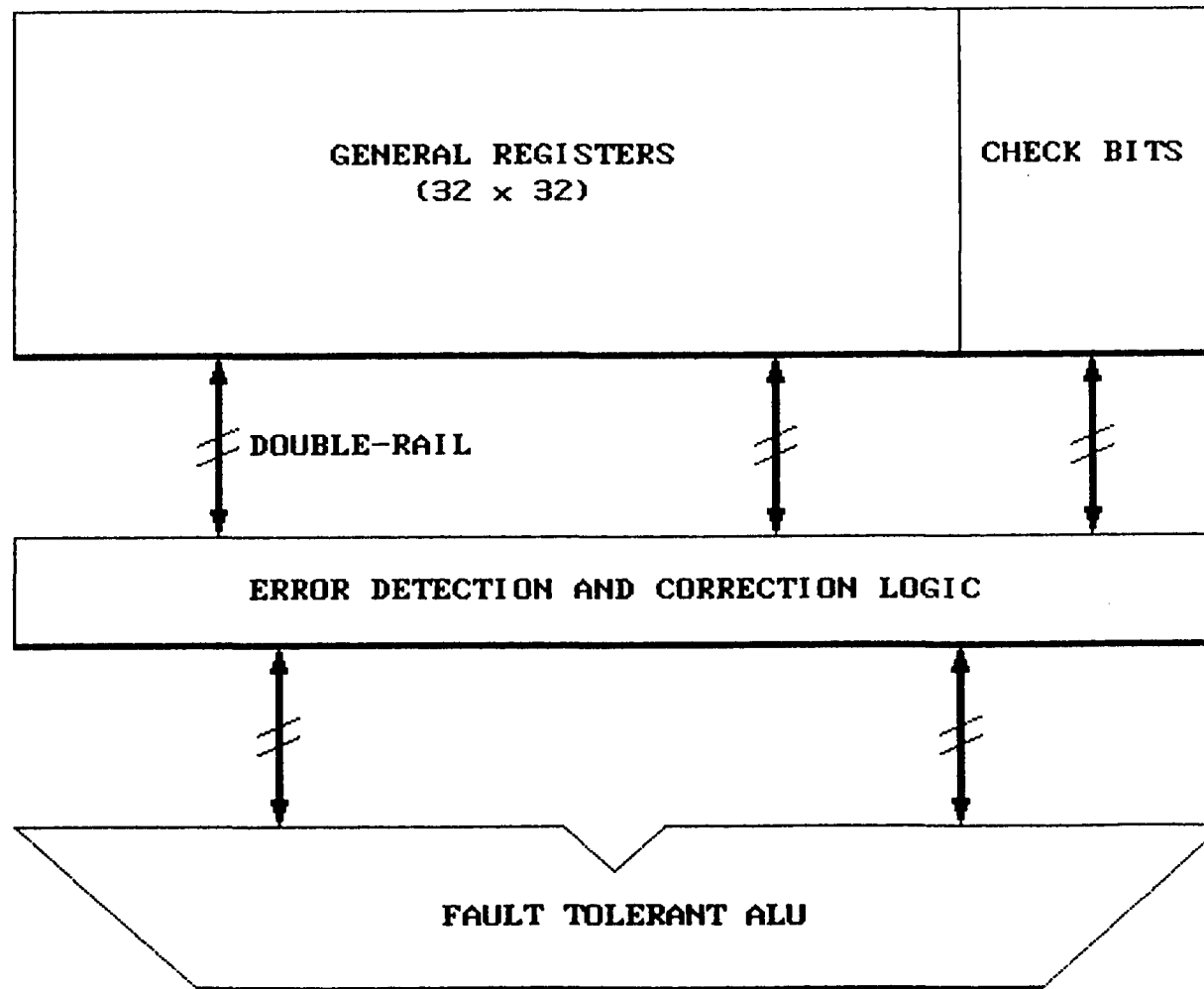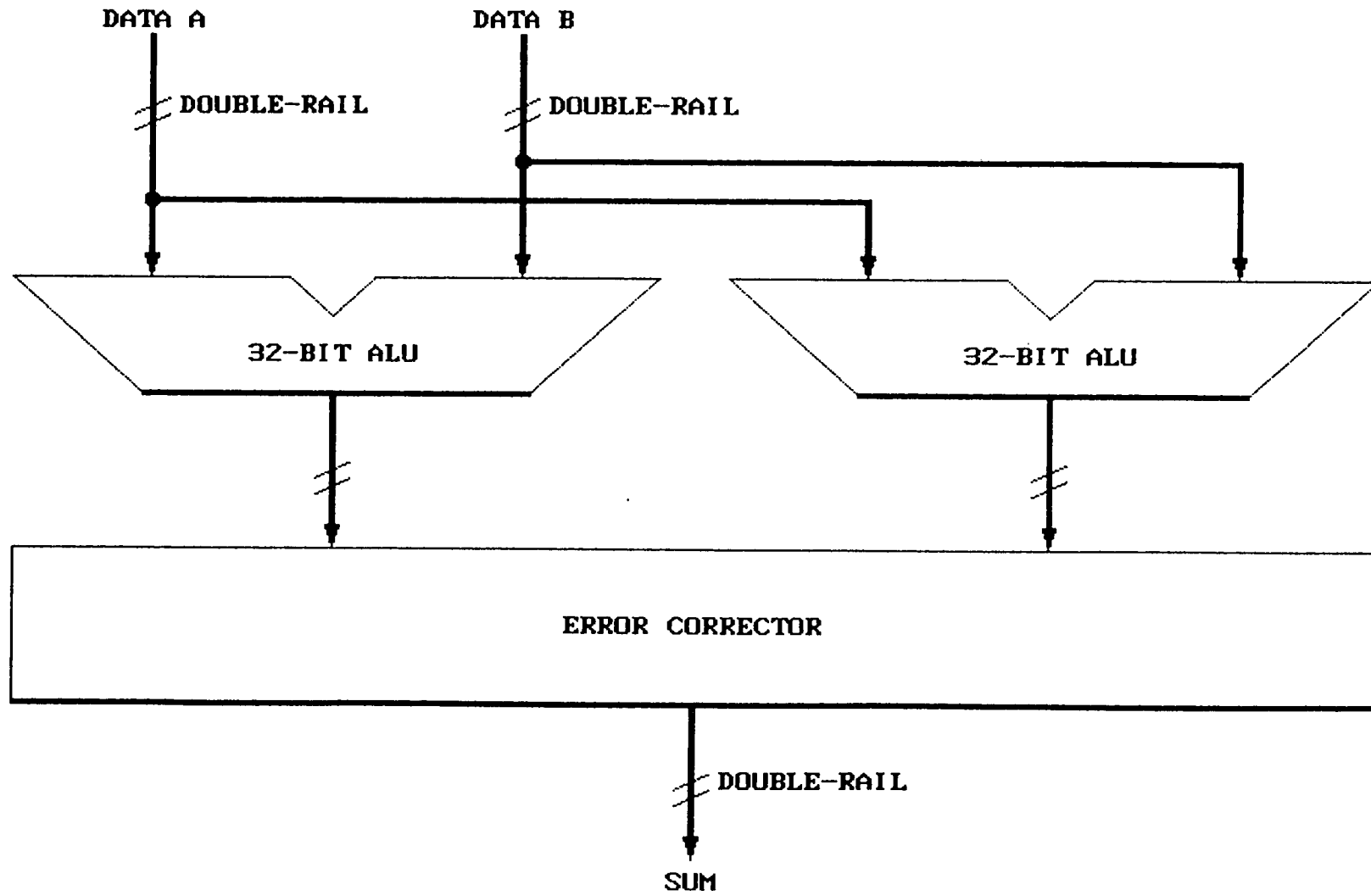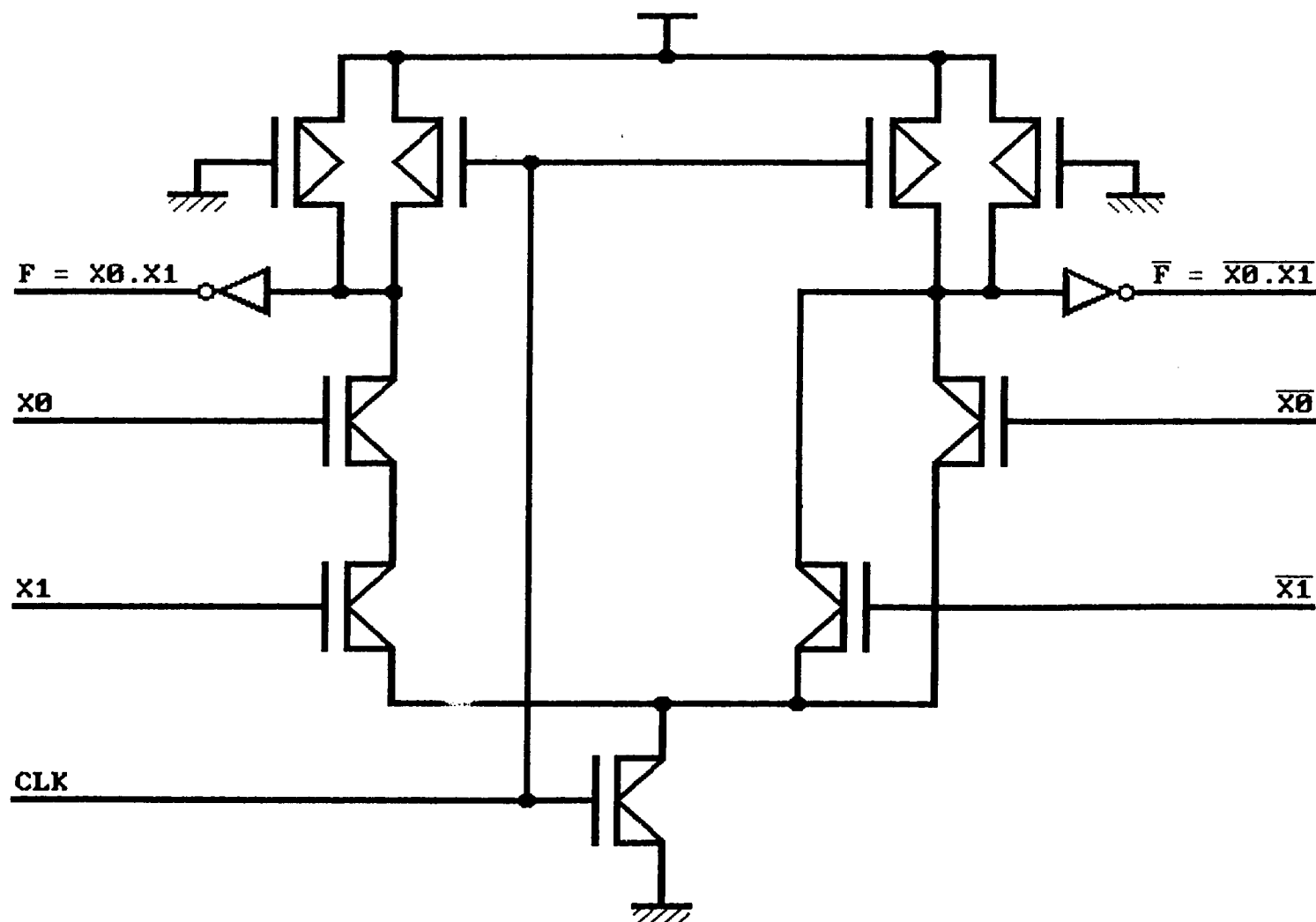
DOUBLE RAIL CMOS LOGIC
(GOOD CIRCUIT)

0

1

1

0

0

1

CLK
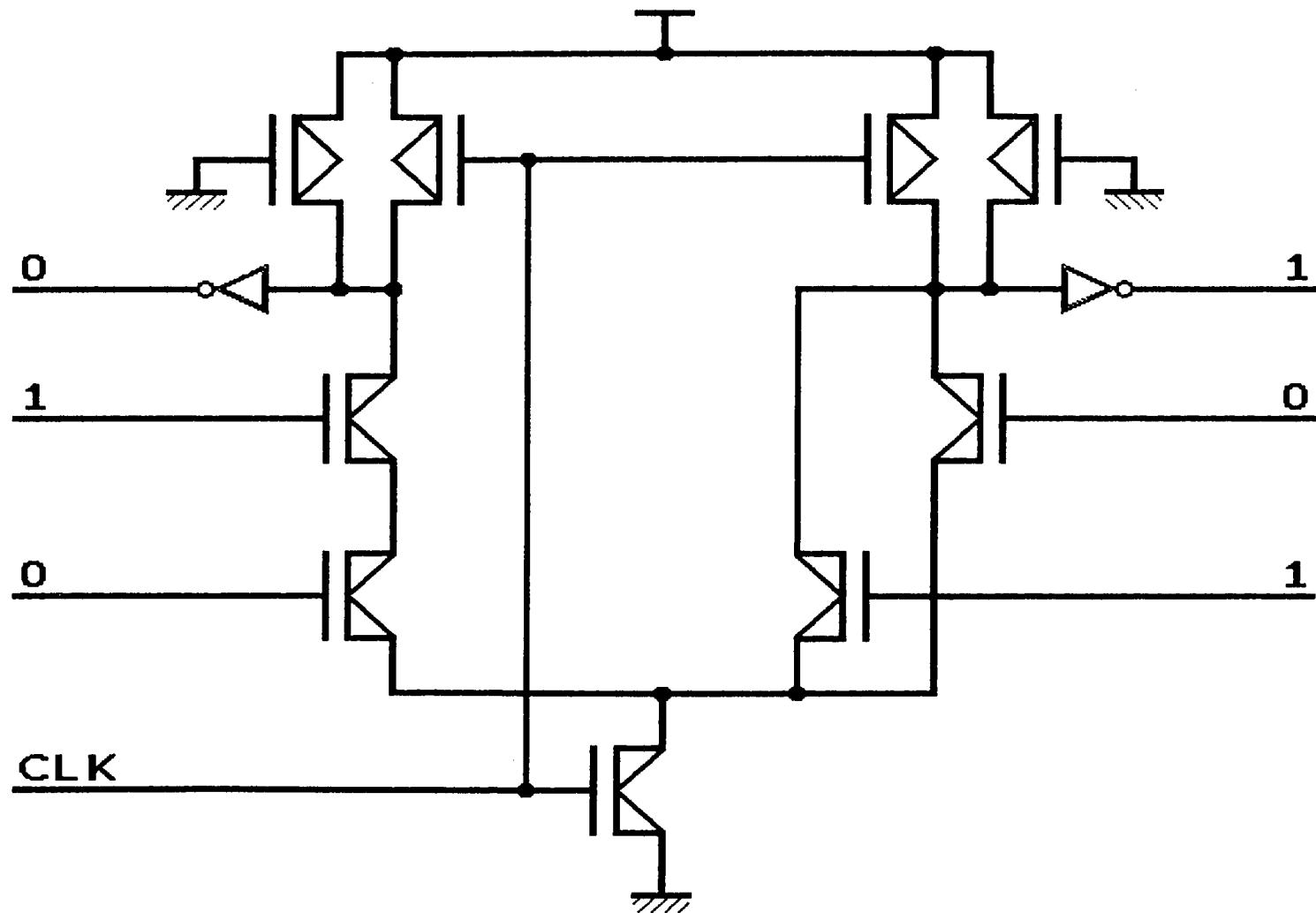
DOUBLE RAIL CMOS LOGIC
(TRANSISTOR STUCK-ON)

DOUBLE RAIL CMOS LOGIC
(TRANSISTOR STUCK-OFF)

High Rate
Science Data Handling

JPL
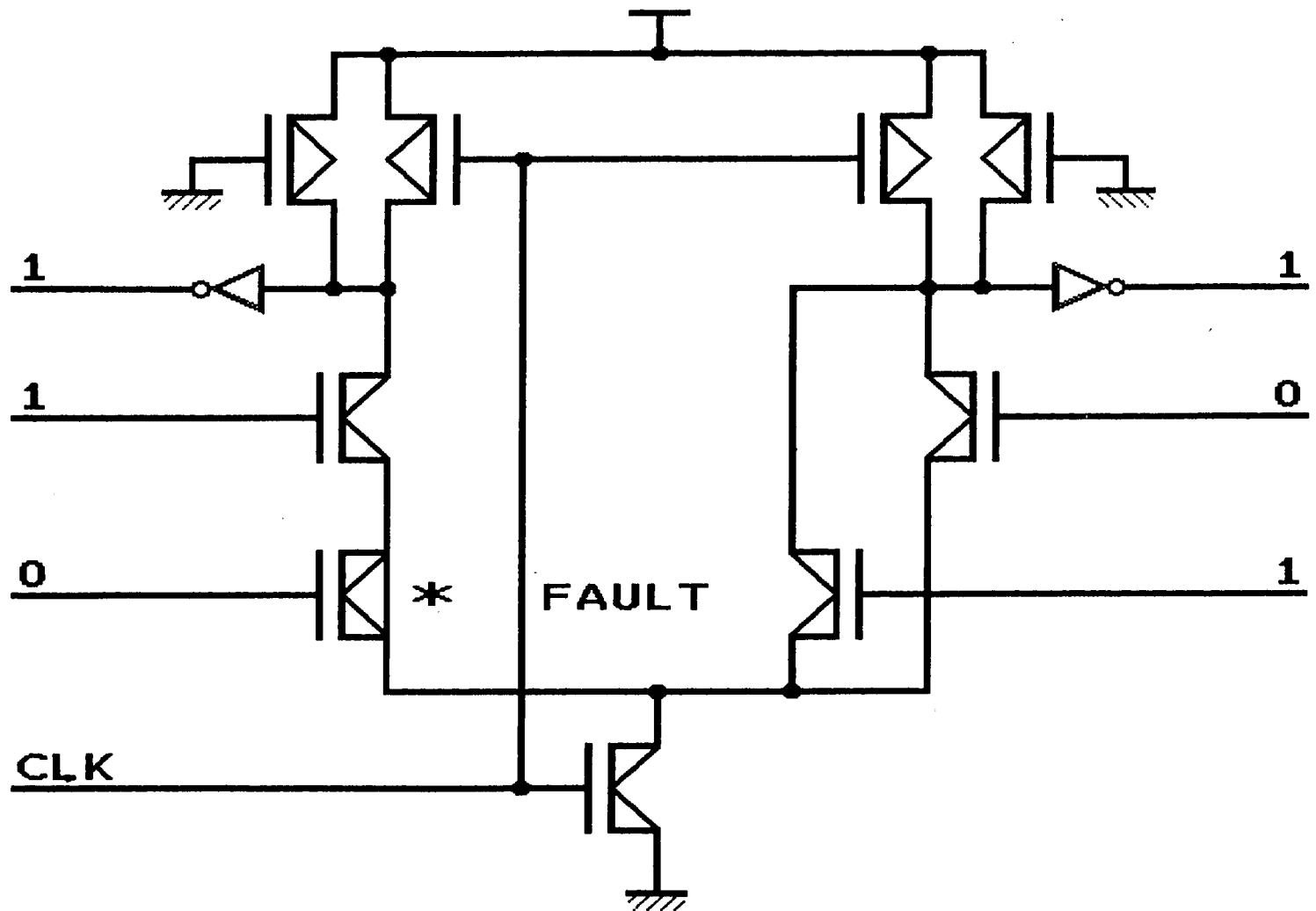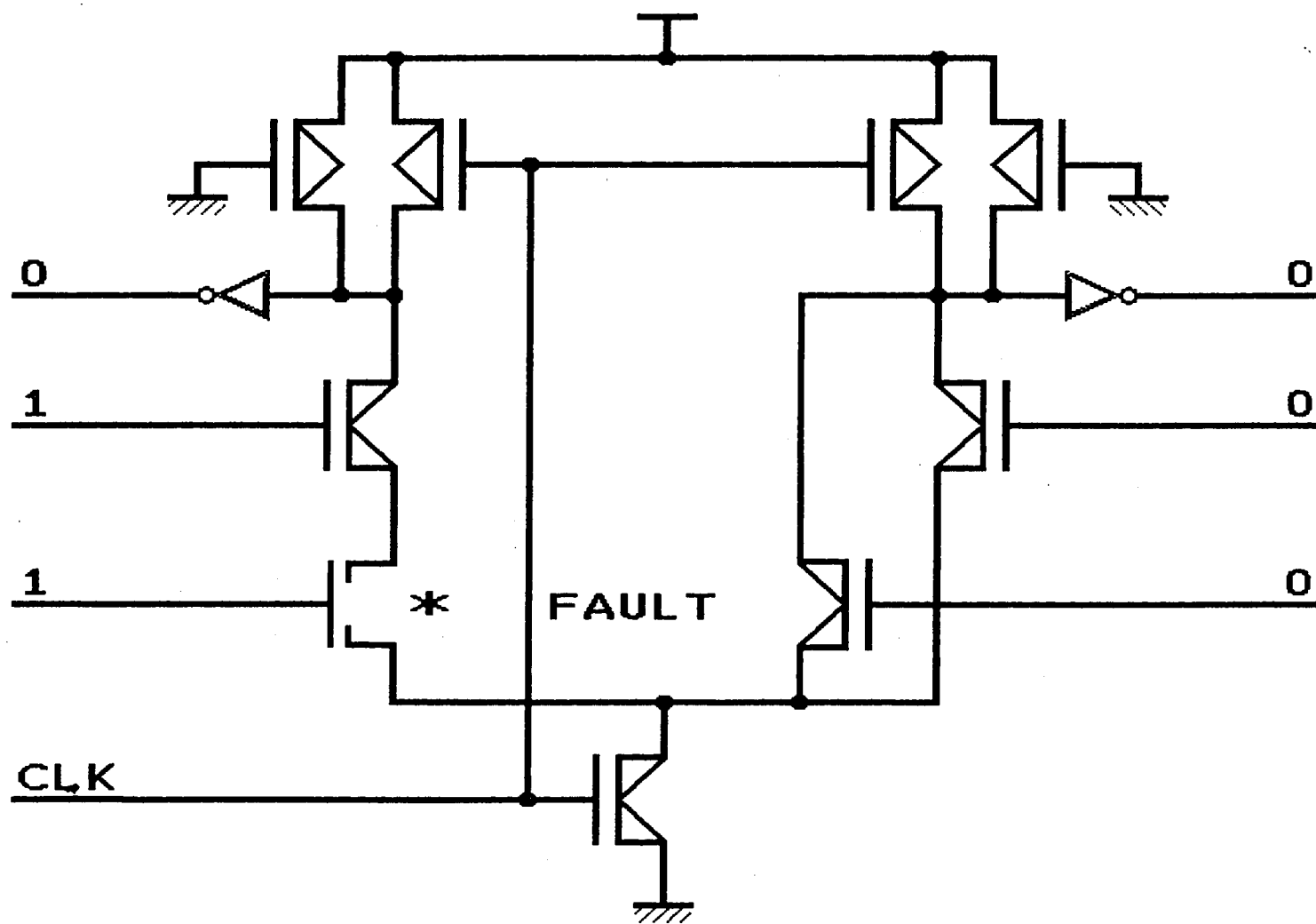
Richard Masline
January 16, 1990

JPL HIGH RATE SCIENCE DATA HANDLING

- Performed under the auspices (and funding) of the PE&A office.

- Documented in "Data Handling Options for Space Station Freedom
  Program Office", JPL Document No. JPL D-6746, dated September 19, 1989.

- Methodology
  - Identify User Requirements
  - Establish Baseline SSF capability
  - Evaluate experiments' requirements
  - Identify shortfalls
  - Locate new and emerging technologies that may address problems
  - Develop a system architecture that addresses the problems

JPL

SCIENCE NEEDS

VERSUS

TECHNOLOGY

113

- Experiment Needs

  - 2K X 2K by 8 bit • 1000 frames/sec (Fps)
    Mass Transport
  - 1K X 500K by 5 bit • 1000 Fps
    Thermophysical Measurements
  - 3K X 1K by 4 bit • 2000 Fps
    Micogravity Combustion
  - 5K X 5K by 8 bit • 1000 Fps
    Crystallization of Spheres
  - 200K X 266K by 4 bit • 6000 Fps
    Pool boiling
  - 10K X 10K by 8 bit • 1,000,000 Fps
    Containerless Processing
    SCRAM

  Plus a whole host of other rates

- SSF Provisions

  - NTSC - 256K X 256K at 30 Fps
    Broadcast quality
    512K x 512K at 30 Fps
    Studio quality

  - HDTV - Approximately 1K X 1K at 30 Fps
    Broadcast quality
    1K X 1K at 60 Fps
    Studio quality

- Best ruggedized display 2K X 2K at 72 Fps

- Are the needs achieveable?

  Yes, by Film:

  The comparison of film resolution to pixel resolution of
  a CCD is very difficult. After discussions with scientists at
  Kodak, I developed an understanding that the boundaries of
  film resolution are best represented by an ellipse on this
  chart. Variables such as light source, temperature,
  handling, time, processing, backing, grain size, etc. affect
  the results.
  If one were to go by line pair resolution figures, then
  16MM might be considered to produce a resolution of 26K X
  20K. This is not a realistic calculation. Reality is much less
  than that, but published comparisons have not been found.

- Are there solutions if we are not going to fly film in SSF?

  Yes, work is progressing toward fast, large, digital CCD focal
  planes:

  - Kodak is producing a 2K X 2K focal plane based on their megapixel
    camera, which their scientists believe can be developed to a 1000
    Fps camera.

  - Ford Aerospace has a 4K X 4K focal plane which could be developed
    to run at 1000 Fps.

  - Q-Dot has test units designed to run at 1000 Fps, which they plan to
    evolve into 10,000 Fps.

SCIENCE NEEDS VRS TECHNOLOGY

115
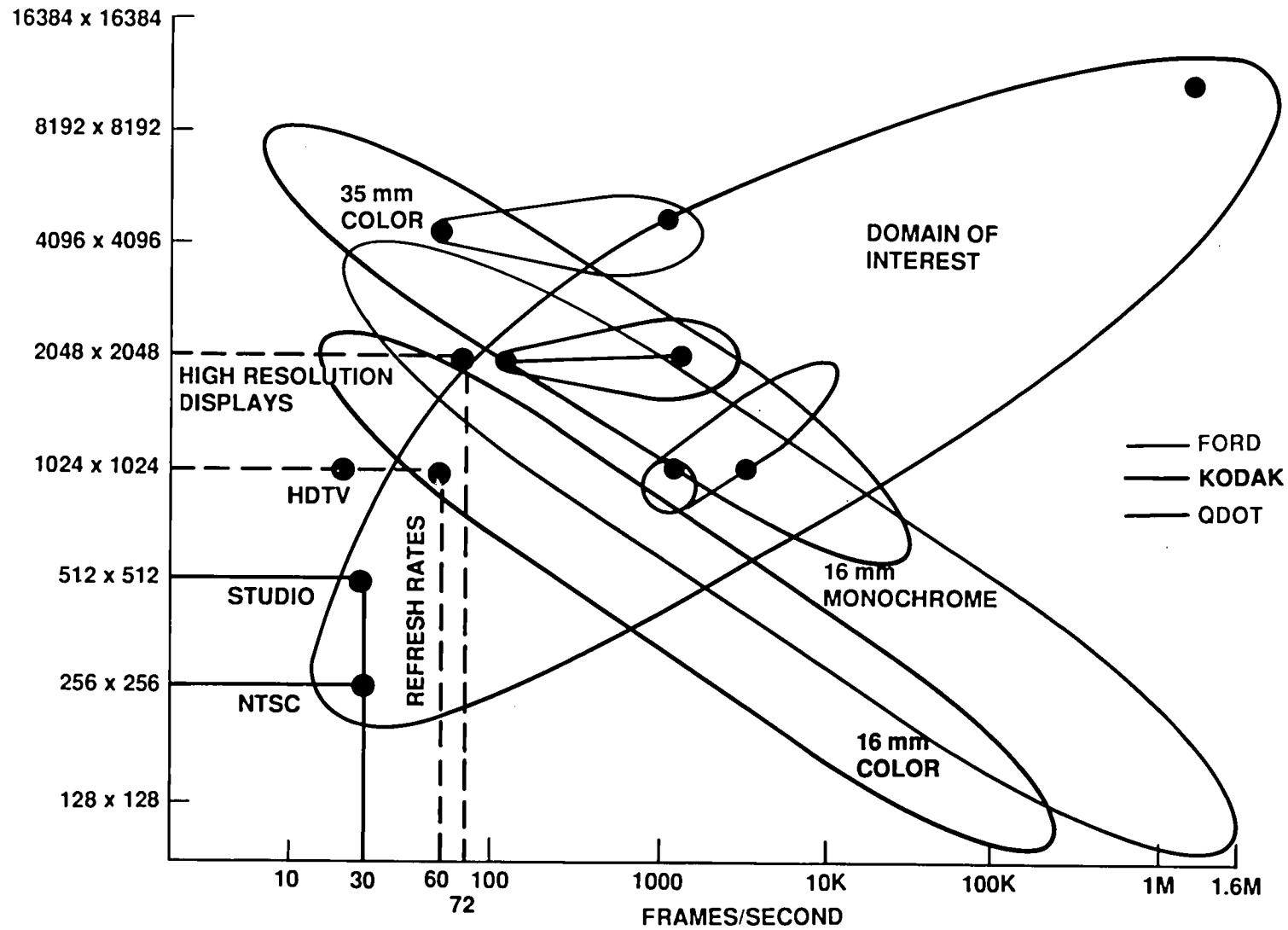
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JPL

TECHNOLOGY ASSESSMENT

◢PL HIGH RATE SCIENCE DATA HANDLING

TECHNOLOGY ASSESSMENT

This chart has no vertical axis. The only axis is the horizontal one, which is calibrated in bits per second on a logarithmic scale. The bits per second is the input or output rate of the devices under consideration.

- There are listed various camera configurations on the left which address the needs on the previous chart.

- The fastest commercially available camera, 192 X 240 @ 2000 Fps, is from Spin Physics.

- The rates of output of these cameras far exceed the Spin Physics camera system.

- They exceed the capabity of FDDI and TDRSS by even larger margins.

- What can be done to close this gap?

  - Transport the data - Fiber technology
    1 Gigabit and greater

  - Process the data
    MCNC - Blitzen chip - 10 GByte/sec I/O
    AMT - DAP 620+ - 1.6 GByte/sec I/O

  - Record the data
    1.9 GByte/sec ingest rate

  - Downlink the data
    1-5 Gbit downlinks can be built
    Airborne receipt can be done

  - Optical holographic memories

TECHNOLOGY ASSESSMENT

10K x 10K AT IM FPS
BY 8 BITS

OPTICAL HOLOGRAPHIC
MEMORIES

UNISYS
DOWNLINK

RECORDERS
RAM IN 6.25 in.^{2}
HOECHST-CELANESE
BY 24 BITS
2K x 2K AT 1000 FPS
BY 8 BITS
BY 32 BITS
1.3K x 1K AT 1000 FPS
BY 8BITS
1K x 1K AT 1000 FPS
BY 8 BITS
BLITZEN BY MCNC
AT&T
ULTRA
SCS

192 x 240 AT 2000 FPS
BY 8 BITS

FDDI
SSF DOMAIN
TDRSS

—— PROCESSING
    SWITCHING DOMAIN

—— FIBER TECHNOLOGY

—— STATED EXPERIMENTAL
    DOMAIN

10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15}

BITS PER SECOND

119
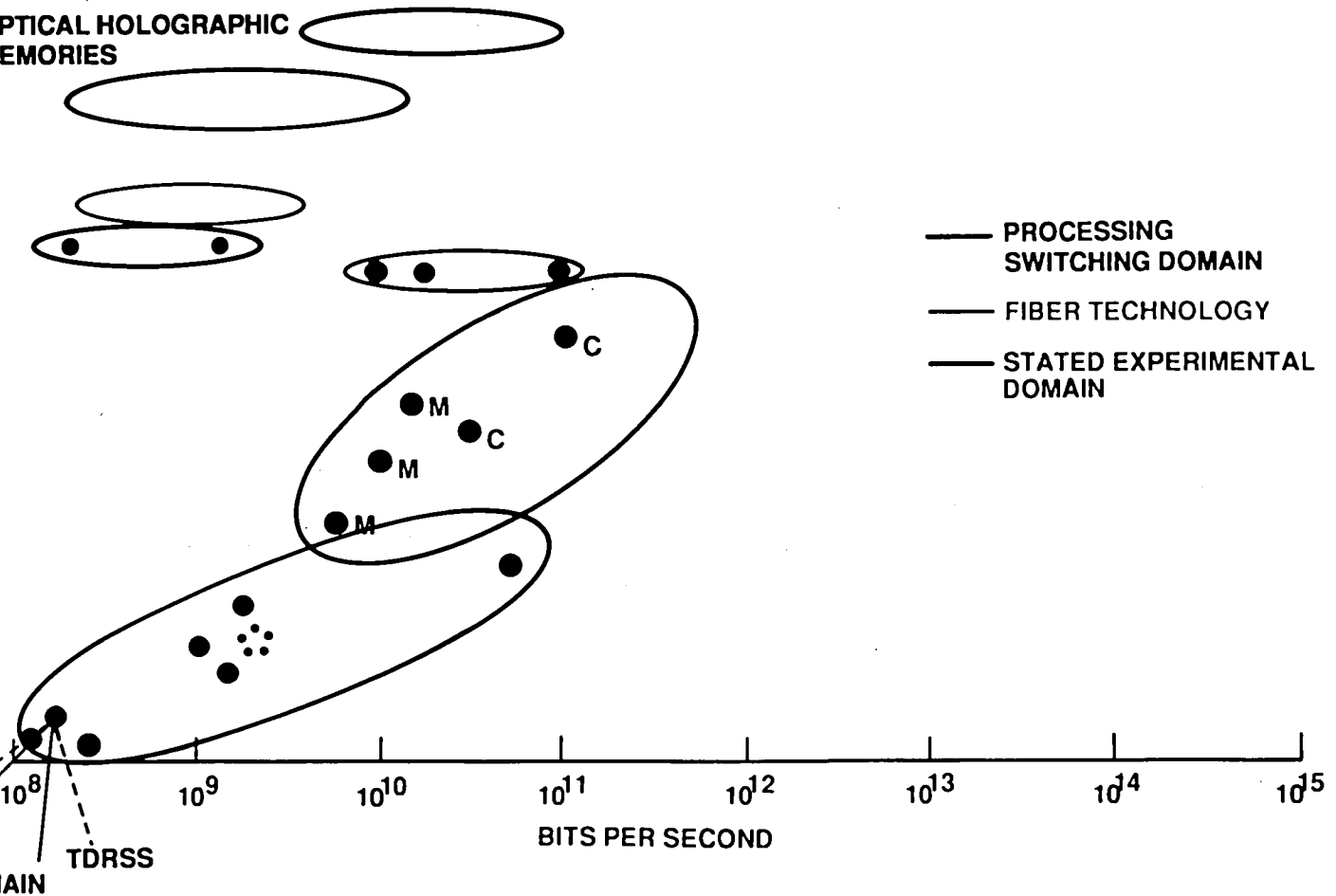
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CONCEPTUAL ARCHITECTURE

- **Begin with SSF baseline**
    Experiment
    DMS
    C&T

- **Add:**

    1. A control structure. This could reside within the DMS, but we did not wish to alter the DMS.
    2. Camera to view the experiment
    3. Processors
        - Camera head
        - Router or switch
        - Image analysis
    4. Network (may include the router in 3)
    5. Recorders
    6. Random store – Holographic memory or parallel disk
    7. Direct downlink

122

Conceptual Architecture

Core LAN

Payload LAN

DMS

Schedule
Command
Status Etc.

Crossbar Control

C&T

100-300 Mbps

Crossbar Switch

Experiment

Camera

Camera Head Processor

2 Gbps

Delta Frame
Moving Window
Variable Size
Variable Aspect Ratio
Variable Resolution

100-300 Mbps

2 Gbps

400 Mbps - 1.9 Gbps

Optical Delay Line

Direct Downlink

400 Mbps - 1.9 Gbps

Delta/Fourier/Hadamard Transforms, Etc.
Image Identification
Phenomenon Recognition
Image Compression
Image Time Series

Image Analysis & Compression Processor

Recorder

Removable Media

Data Base

100-300 Mbps

Baseline Design

Data Flow

Control

123

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124

JPL

DIRECT DOWNLINK
CONCEPT

ANTENNA PLACEMENT

PHASED ARRAY
OF ANTENNAS

ARRAY OF
FIVE ANTENNAS
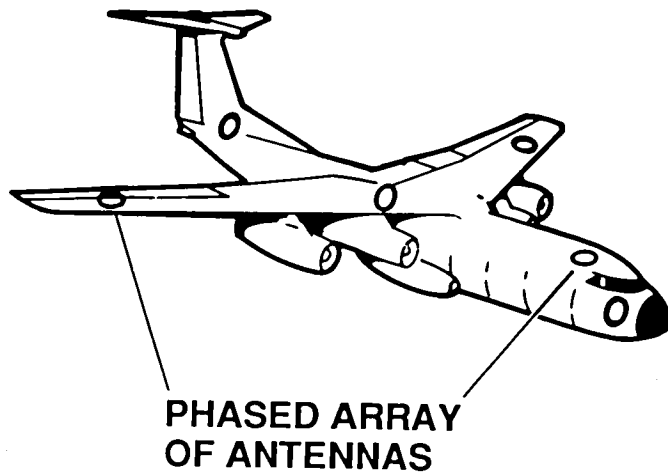
ON AIRCRAFT

ON SPACE STATION

126
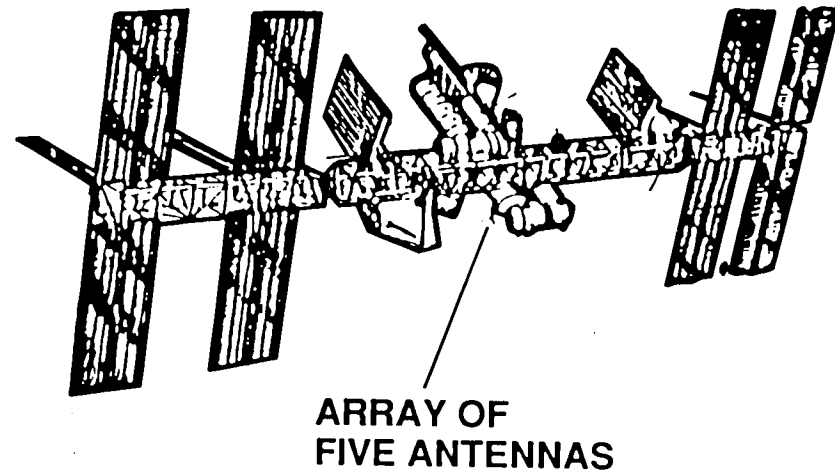
CONCEPTUAL FLY-UNDER

POLAR PLATFORMS

SPACE STATION

RECEIVING ANTENNA
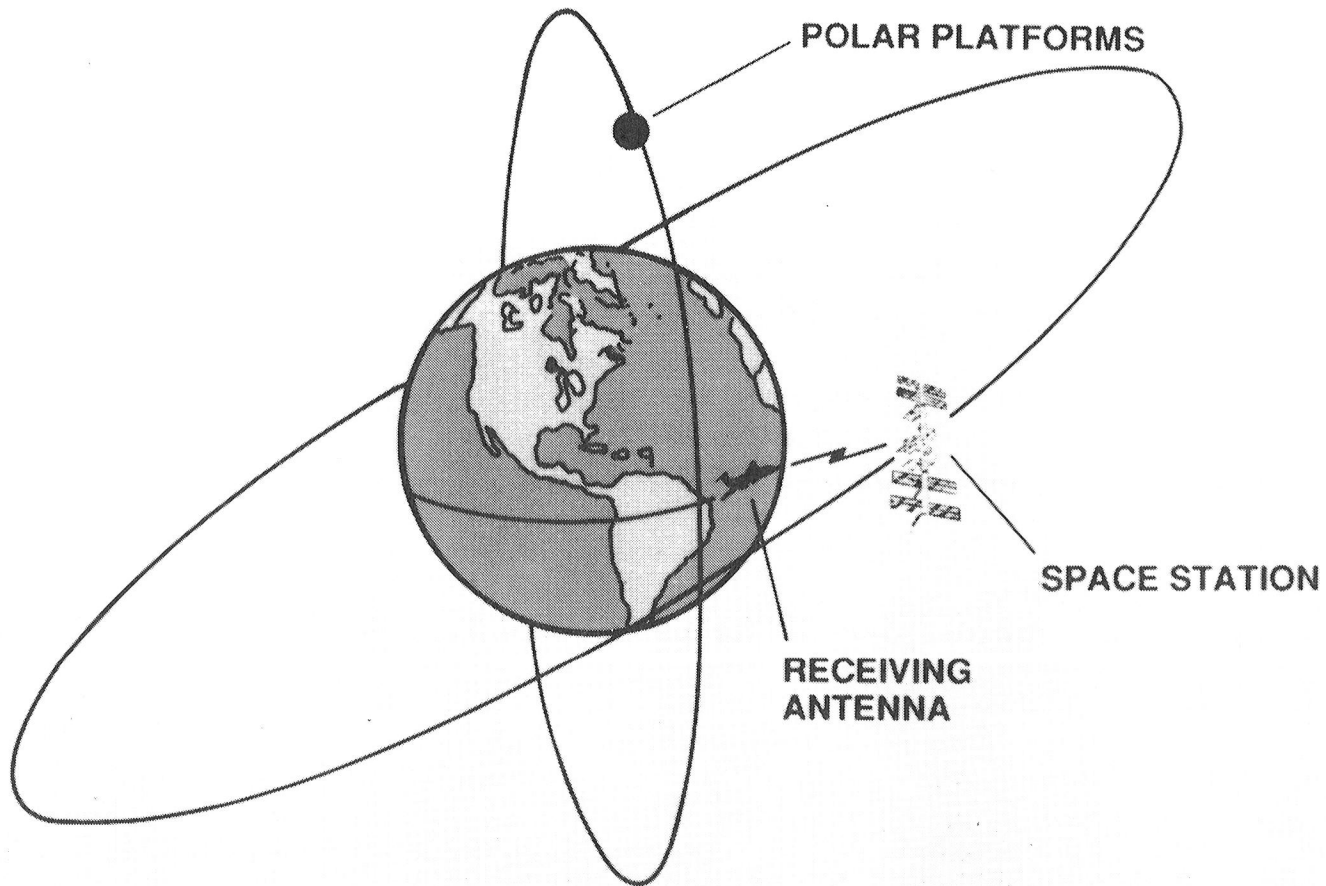
CONCLUSIONS

- Science needs will exceed capacity of existing or planned systems to transmit to earth.

- Capability to generate image data will continue to exceed capacity to transmit to earth.

- The need for mechanisms to capture, route, process, manage, analyze and store High Rate Data are common to many experiments.

- Technology for these mechanisms can be made available.

- The scientist must actively participate in the development.

- The system must be easily adaptable to changes in requirements and technology.

NASA
LaRC

TECHNOLOGY FOR SPACE STATION EVOLUTION

OPTICAL DISK TECHNOLOGY

SPACEFLIGHT OPTICAL DISK RECORDER

SODR

PAMELA RINSLAND

NASA LANGLEY RESEARCH CENTER

January 16, 1990

SPACEFLIGHT OPTICAL DISK RECORDER

A NASA program to develop a high performance (high rate, high capacity) rewriteable optical disk recorder focused on use aboard unmanned polar orbiting platforms is underway at Langley Research Center. An expandable system concept is proposed consisting of multiple drive modules and a modular controller. System goals are 160 gigabyte capacity at up to 1.2 gigabits per second, concurrent I/O, varying data rates, and five year operating life in orbit. Drive performance goals are 10 gigabyte capacity, 300 megabit/second transfer rate, 10^{-10} corrected BER and 250 millisecond access time.

Although development is currently focused on Eos polar orbiting platforms, the SODR is an enabling capability for many future missions, such as Space Shuttle and Space Station Freedom payloads, Mars Rover, and polar and geostationary orbiting platforms. A possible Space Station application for SODR is that of a dedicated resource to store the high speed optical data recorded and transmitted from microgravity science experiments. Surveys conducted for a workshop sponsored by NASA-Lewis in May 1988 show that a minimally configured SODR can meet the requirements of many of the investigators.

3.1--SPACEFLIGHT OPTICAL DISK RECORDER (SODR)

OBJECTIVE

Develop and demonstrate components and subsystems required to provide high-performance (high rate, high capacity) random file access storage systems based on erasable optical disk technology for future spaceflight missions. This includes development of magneto-optic disk media, diode laser array, write/read/erase electro-optic head, disk drive unit, and system controller.

DESCRIPTION

Key technologies that form the basis for the system are 14-inch magneto-optic media, 9-element diode laser arrays, multi-track electro-optic head, and versatile system controller. The areal density (bit/area) of optical media, is projected to be eight to twenty times that of magnetic media. The SODR goal is 10 gigabit per disk. The use of a diode array and supporting electro-optic head to write, read, and erase eight simultaneous data tracks on each surface provides high data rate. The per head goal is 150 megabits/sec or 300 megabit/drive. The concept is a dual-sided disk, two heads, and supporting electronics into a disk drive package. An associated modular controller is to be developed to produce a configurable, expandable system which can provide up to one gigabit/sec rates and 1.2 terabit capacities.

NASA RATIONALE AND BENEFIT

High performance random file access storage is an enhancing and enabling capability. The current program focus is application aboard Polar Orbiting Platforms in support of the Earth Observing System. High performance optical recording has potential payoff to many major NASA programs including the Space Transportation System, Space Station, including GEO and Polar Platforms, Space Science and Exploration (e.g., Mars Rover and Lunar Base). There are potential benefits to DoD space programs, ground based Government and commercial programs, and the establishment of national leadership in critical technology areas.

STATUS / ACCOMPLISHMENTS

Feasibility was demonstrated in the lab in 1988. This year the SODR program has developed a new laser structure, delivered improved lasers with 100 hour burn in, completed preliminary environmental testing of aluminum and glass media with glass selected as the new baseline, continued characterization and enhancement of the breadboard drive redefined goals of a drive brassboard reflecting DoD participation, established requirements and initiated breadboard controller design.

Technical Contact: Tom Shull, LaRC, (804)864-1874 (FTS 928-1874)

The SODR program is sponsored by NASA's Office of Aeronautics and Space Technology and managed by Langley Research Center. The objective is to develop and demonstrate the technology,components and subsystems needed to achieve rewriteable optical disk mass storage systems for space flight applications. The fundamental elements associated with this development include the following: a) 14 inch dual-sided magneto-optic (MO) media, b) independently addressable 10-element solid state laser diode arrays, c) an eight data track electro-optic (EO) head and d) electronic and mechanical drive subsystems.

Media studies have addressed the MO performance and suitability of glass versus aluminum substrates for harsh environments. Tests included vibration, thermal cycling and outgassing. A blank glass disk survived 62 G rms random vibration. Results indicate that glass is the preferred substrate from both a performance and cost viewpoint.

Laser development is focused on longevity and yield improvements. This includes fine tuning of the laser structure and process refinement. Conversion to a new growth technique is being considered. Techniques are being studied to stabilize the lasing frequency that can shift due to optical feedback and aging.

The current spot geometry and spacing on the 14 inch disk support a capacity of 5 gigabytes per side. The disk is formatted in a continuous spiral consisting of preformatted permanent pilot track that contains the radius (track number) identification data. This enables closed loop recording and playback that cannot be achieved with a concentric ring pattern. The permanent pilot track lies in the center of a data band of eight rewriteable tracks 1.4 μm apart. There is a 2.1 μm guard band between data bands to accommodate the laser's 0.7 μm spot diameter.

KEY TECHNOLOGIES

NASA
LaRC

PERMANENT PILOT TRACK
EIGHT DATA TRACKS
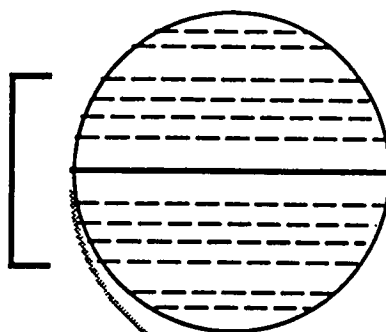
LASER
DIODE
ARRAY

ELECTRO-OPTIC HEAD

14-INCH
REWRITEABLE
MEDIA

SPACEFLIGHT OPTICAL DISK RECORDER

133

Each SODR drive contains one 14" dual sided storage disk. The concept of a storage module refers to two drives mounted with counter rotating disks for angular momentum compensation. One disk surface and its associated hardware are referred to as a device (two devices per drive). In the current design the device is the minimum functional unit. The minimum deliverable physical unit is a drive. The physical device contains the media and its supporting mechanisms. This includes the optical heads, rotating disks, photodetectors, and the support subsystems (mechanical, optical and electronic) needed to read or write information on the media. The goal for each drive is 10 Gigabytes of data capacity and 300 Mbps data throughput.

Drive specific functions required to transfer data from the user to the medium will be performed within the storage module. These include sector mapping, data encoding, error detection and correction (EDAC), buffering, overhead formatting, and command interpretations (seek, read, write and erase).

The physical characteristics of the projected flight drive (dual device and device controller) are as follows:

	DEVICE	CONTROLLER
SIZE:	3/4 FT	1/4 FT
WEIGHT:	45 LBS	15 LBS
POWER: Write 150	50 W	50 W
Write 300	70 W	100 W
Read 150	75 W	50 W
Read 300	130 W	100 W
Erase 300	70 W	0 W

ANGULAR MOMENTUM: 1 FT-LB-S
OVERALL DIMENSIONS: 15.3" x 6.5" x 17.9"

DISK DRIVE

ELECTRO OPTIC HEAD
(SURFACE 1)

ELECTRO OPTIC HEAD
(SURFACE 2)

14" MO DISK
(TWO SURFACES)
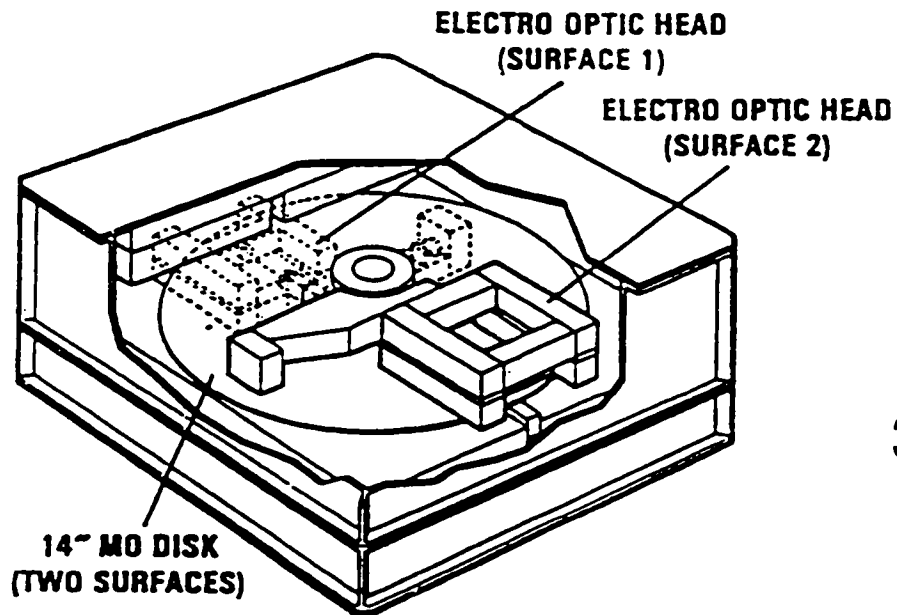
PERFORMANCE GOALS

10 GIGABYTE CAPACITY
300 MEGABIT PER SECOND
250 MILLISECOND ACCESS

The SODR is an expandable modular system which consists of a modular SODR Controller and multiple storage modules. Current plans are to design and build the SODR Controller at LaRC and to obtain the storage module design and development through outside sources. The SODR can be modularly configured to provide up to 1.8 gigabits per second data transfer rate and up to 160 gigabyte capacity.

The primary functional requirements of the SODR Controller are flexibility, high data rate, high capacity, simultaneous I/O through multiple ports, random access to files, and high reliability. Flexibility will be provided by the system's modularity that allows the system to be configured to meet different application requirements. Random access to data is an inherent feature in disk storage systems. This feature will be provided by the controller in the form of random access to files. The primary goals for system reliability include up to 10^{-12} corrected BER and a minimum of two to five years operating life in orbit.

The SODR Controller will perform standard data transfer functions such as directory management, resource allocation and scheduling that remove the user from the physical details of the storage modules. There are differences between the SODR Controller and other high performance controllers. The SODR Controller also provides higher and variable data transfer rates, contains a greater number of modules (more than eight), and supports dynamic reconfiguration, fault tolerance, adaptable file management philosophy and reprogrammable system algorithms. Also, the command and data ports are separated to achieve the desired reconfigurability and data throughput.

SYSTEM CONCEPT

NASA
LaRC

DISK DRIVE

DISK DRIVE

ELECTRONICS

CONTROLLER

STORAGE MODULES

137
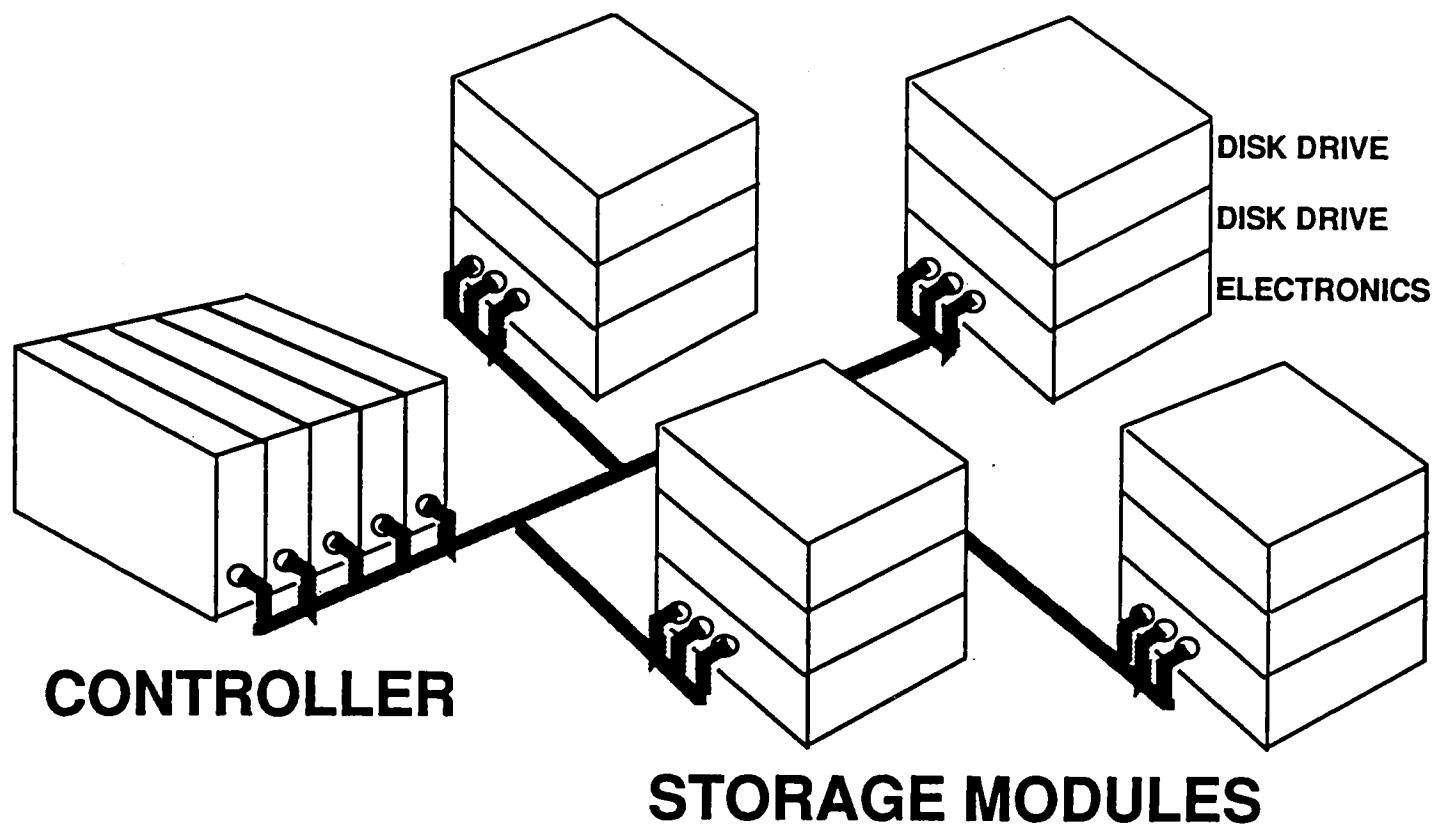
SPACEFLIGHT OPTICAL DISK RECORDER

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CONCLUSION

NASA
LaRC

- **TECHNOLOGIES FOR FLIGHT OPTICAL DISK RECORDER HAVE BEEN DEMONSTRATED**

- **BENEFITS TO SPACE STATION IN RELIABILITY, VERSATILITY, AND CAPABILITY**

- **PROGRAM SCHEDULE CAN BE MET WITH APPROPRIATE FUNDING**

SPACEFLIGHT OPTICAL DISK RECORDER

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ELECTRONIC NEURAL NETWORKS

ANIL THAKOOR

JPL

CENTER FOR SPACE MICROELECTRONICS TECHNOLOGY
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

ELECTRONIC NEURAL NETWORKS

JET PROPULSION LABORATORY

BACKGROUND

- NEURAL NETWORKS OFFER A TOTALLY NEW APPROACH TO INFORMATION PROCESSING THAT IS ROBUST, FAULT-TOLERANT, AND FAST.

- MODELS OF NEURAL NETWORKS ARE BASED ON HIGHLY PARALLEL AND DISTRIBUTIVE ARCHITECTURES.

- JPL IS DEVELOPING ELECTRONIC IMPLEMENTATIONS OF ARTIFICIAL NEURAL NETWORKS TO EXPLOIT THEIR EMERGENT PROPERTIES FOR "INTELLIGENT" KNOWLEDGE ENGINEERING APPLICATIONS.

- IN AN ELECTRONIC EMBODIMENT, "NEURONS" ARE REPRESENTED BY THRESHOLD AMPLIFIERS, AND "SYNAPSES" BY RESISTORS. INFORMATION IS STORED IN THE VARYING STRENGTHS OF SYNAPTIC CONNECTIONS.

- ELECTRONIC IMPLEMENTATIONS OF APPLICATION – SPECIFIC HIGH SPEED NEUROPROCESSORS FOR:

    - ASSOCIATIVE RECONSTRUCTION
    - CARTOGRAPHIC ANALYSIS
    - RESOURCE ALLOCATION
    - GLOBAL OPTIMIZATION
    - AUTONOMOUS CONTROL

142

INTRODUCTION

- ARTIFICIAL NEURAL NETWORKS:

    - MASSIVELY PARALLEL ARCHITECTURES INSPIRED
      BY THE NATURE'S APPROACH TO INTELLIGENT
      INFORMATION PROCESSING

- KEY QUESTIONS:

    - WHAT GOOD ARE THEY?

    - CAN THEY DO SOMETHING UNIQUE FOR SPACE
      STATION?

    - WHEN WILL THEY DELIVER?

NUMBERS !

- A HUMAN BRAIN HAS OVER 10^{10} NEURONS AND 10^{14} SYNAPSES.

- HARDWARE IMPLEMENTATIONS TODAY ARE AT ABOUT 10^{3} NEURONS

  AND 10^{5} SYNAPSES.

BUT

- THE BRAIN IS NOT FULLY CONNECTED !

- THE CURRENT ARTIFICIAL NEURAL NETWORKS ARE ALREADY
  PROVING THEMSELVES EXTREMELY USEFUL.

- NEURAL NETWORKS ARE NOT GENERAL PURPOSE COMPUTERS.
  THEY ARE SPECIAL-PURPOSE HIGH PERFORMANCE
  CO-PROCESSORS.

NEURAL NETWORK

BASIC COMPONENTS: NEURONS

SYNAPSES

ELECTRONIC IMPLEMENTATION:

INPUT   NEURON   OUTPUT
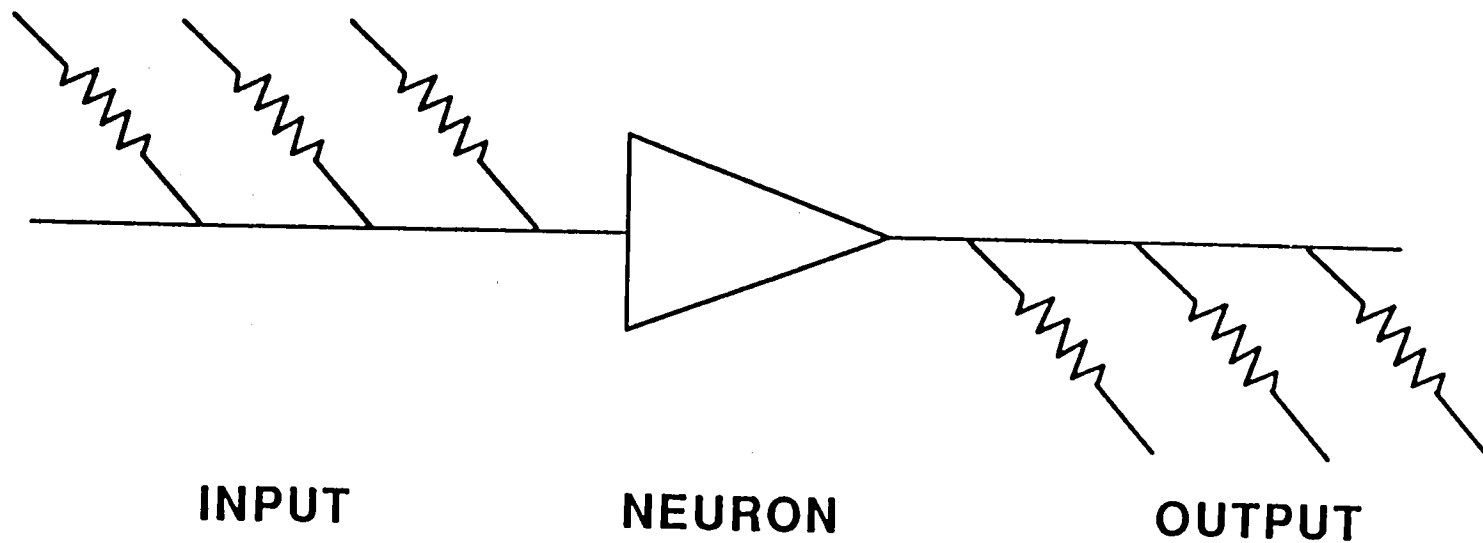
ELECTRONIC NEURAL NETWORKS

JET PROPULSION LABORATORY

NEURAL NETWORK ARCHITECTURES

INPUT

OUTPUT
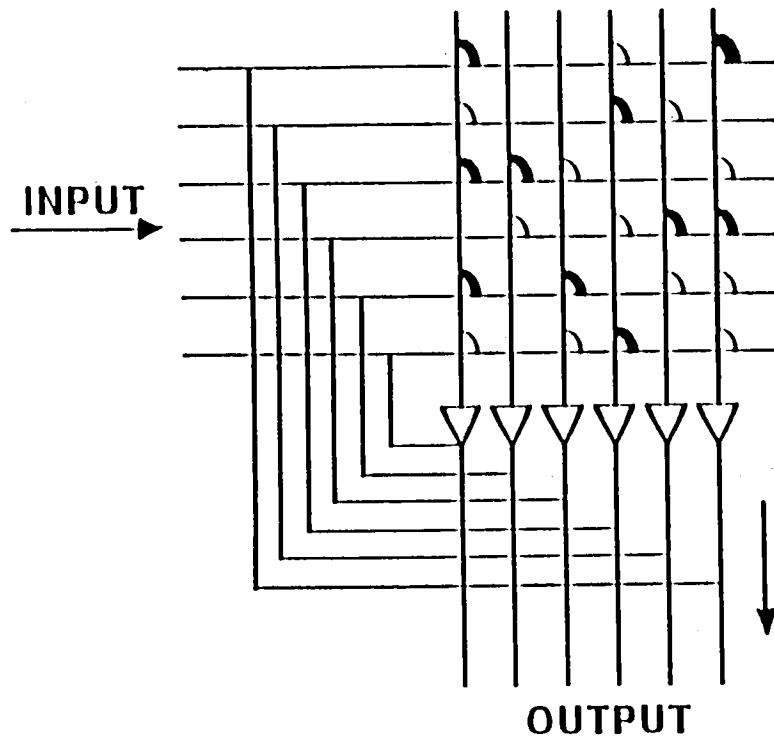
FEEDBACK NETWORK

$$C_i \frac{du_i}{dt} = \sum T_{ij} V_j - \frac{u_i}{R_i} + I_i$$

INPUT

OUTPUT
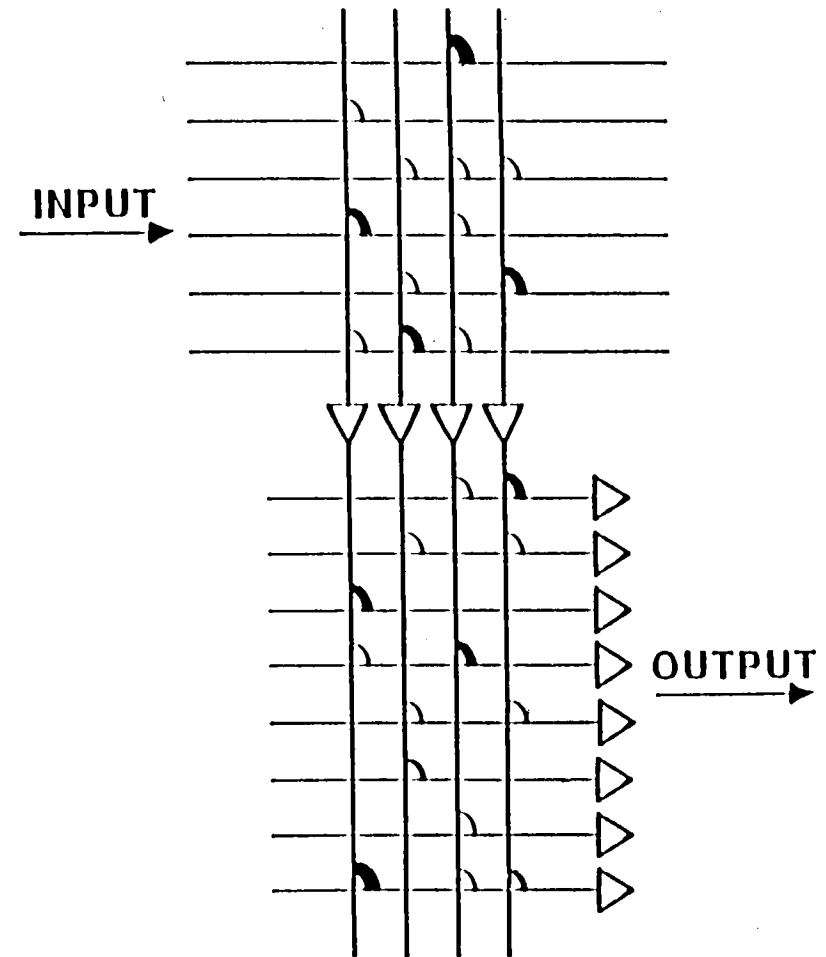
FEEDFORWARD, LAYERED

146

ELECTRONIC IMPLEMENTATIONS

° JPL'S APPROACH HAS BEEN:

    ° TO DEVELOP NEURAL NET "BUILDING BLOCKS" FOR MODULAR HARDWARE

    ° TO VERIFY DESIGN OF NEUROCIRCUITS IN SIMULATION

    ° TO TAILOR "NEUROPROCESSORS" FOR SELECTED APPLICATIONS

° TECHNOLOGIES:

    ° VLSI: CMOS, BIPOLAR, AND EEPROM
                  (FLOATING GATE)

    ° THIN FILM: AMORPHOUS SEMICONDUCTORS, ELECTROCHROMIC
                  MATERIALS, AND CHEMICAL MICROSWITCHES

    ° HYBRID: VLSI/THIN FILM, SINGLE/MULTI-CHIP, WAFER-LEVEL INTEGRATION

147

VLSI/THIN FILM HYBRID HARDWARE
FOR NEUROCOMPUTING

1024 CAPACITOR-REFRESH, ANALOG SYNAPSE CHIP
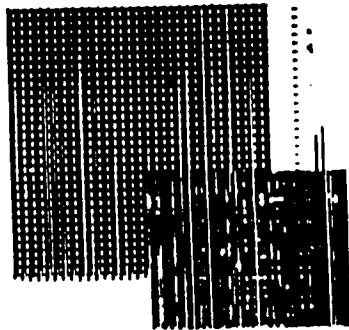
17-NEURON ARRAY CHIP
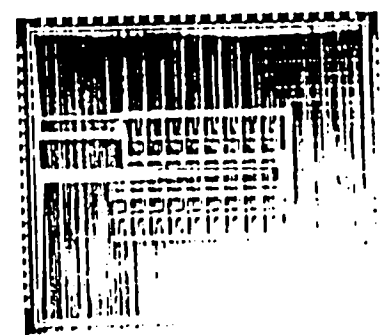
A NEURO-PROCESSOR
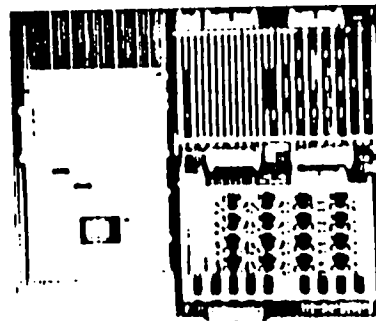
32 x 32 BINARY SYNAPSE CHIP
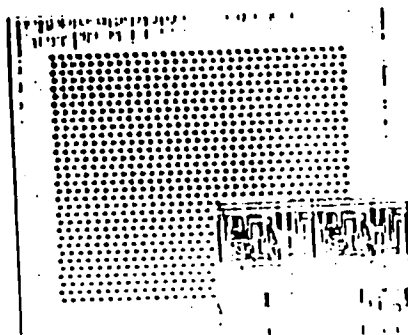
HIGH DENSITY, THIN FILM SYNAPTIC ARRAY
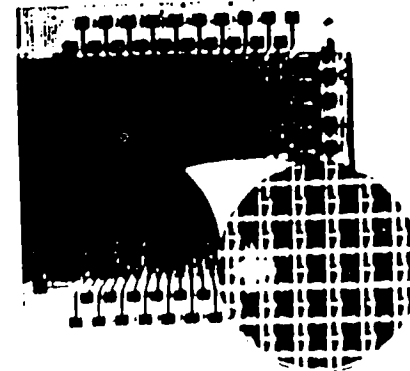
A NEURAL-DIGITAL HYBRID COMPUTER SYSTEM
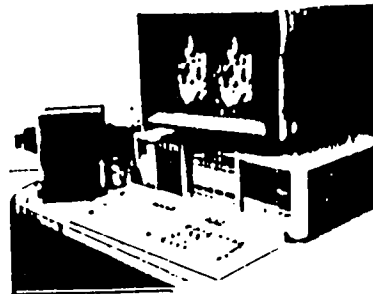
ELECTRONIC NEURAL NETWORKS

JET PROPULSION LABORATORY
CASCADABLE, PROGRAMMABLE, 32 × 32 SYNAPTIC CMOS CHIP
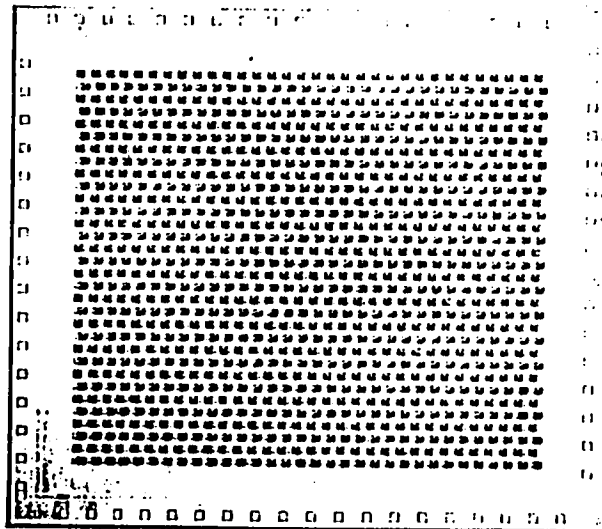
- A BUILDING BLOCK FOR VLSI NEURAL NET HARDWARE

- PROVIDES OVER 10^9 ANALOG OPERATIONS/SEC

- POTENTIAL APPLICATIONS:
  - MULTI SENSOR DATA FUSION
  - ASSOCIATIVE RECONSTRUCTION
  - PATTERN RECOGNITION
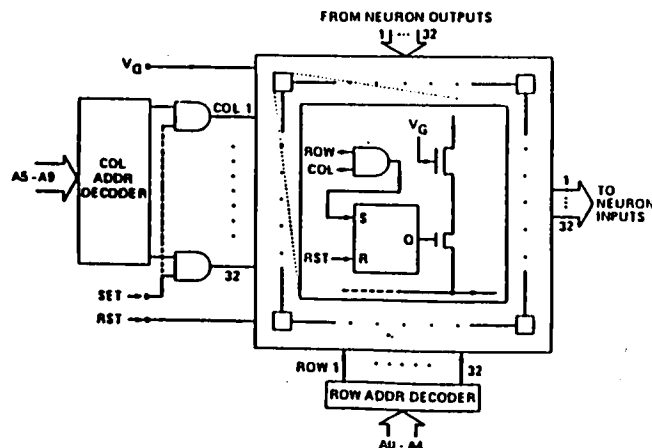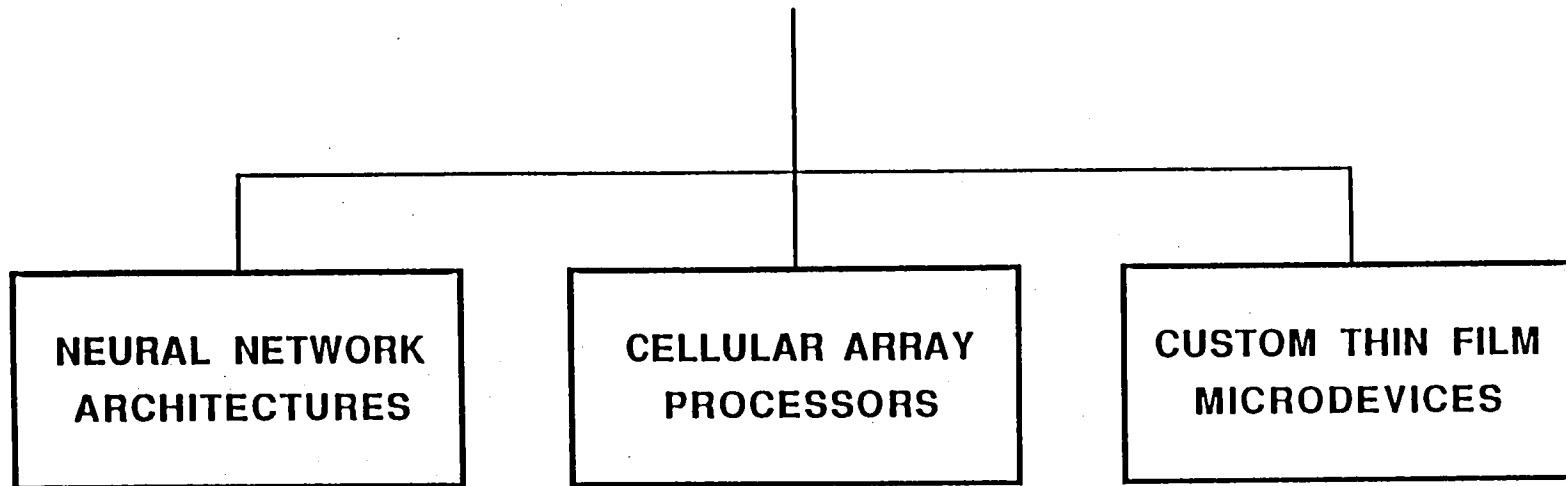
FEATURES OF NEUROPROCESSORS

- APPLICATION-SPECIFIC ARCHITECTURES

- FINE-GRAIN, MASSIVELY PARALLEL, ANALOG, ASYNCHRONOUS PROCESSING

- EXTREMELY HIGH SPEED : TERRA-OPS RANGE

- INHERENT FAULT-TOLERANCE

- UNIQUE CAPABILITIES TO "LEARN" FROM EXPERIENCE AND SELF-ORGANIZE

- TRULY ENABLING NATURE, COMPLEMENTING THE ABILITIES OF HIGH SPEED DIGITAL MACHINES

151

APPLICATIONS OF NEUROPROCESSORS

- AUTOMATION AND ROBOTICS

- ON-BOARD, REAL-TIME, GLOBAL OPTIMIZATION

    - ALLOCATION AND MANAGEMENT OF RESOURCES

- AUTONOMOUS, SCHEDULING, SEQUENCING, AND EVENT-DRIVEN MISSION REPLANNING

- SCIENCE DATA ANALYSIS AND MANAGEMENT

    - PATTERN RECOGNITION, CLASSIFICATION
    - MODELING OF LARGE SYSTEMS
    - CODING, DECODING, ASSOCIATIVE RECONSTRUCTION FROM CORRUPT DATA

152

Neural network classification results. Each color denotes a particular decision or classification for a pixel. e.g., green = "GO", yellow = "GO SLOW", orange = "GO VERY SLOW", and red = "NO GO".

A set of four ... Each color represents a particular ...

153

NEURAL NETWORK HARDWARE FOR TERRAIN TRAFFICABILITY DETERMINATION

JPL
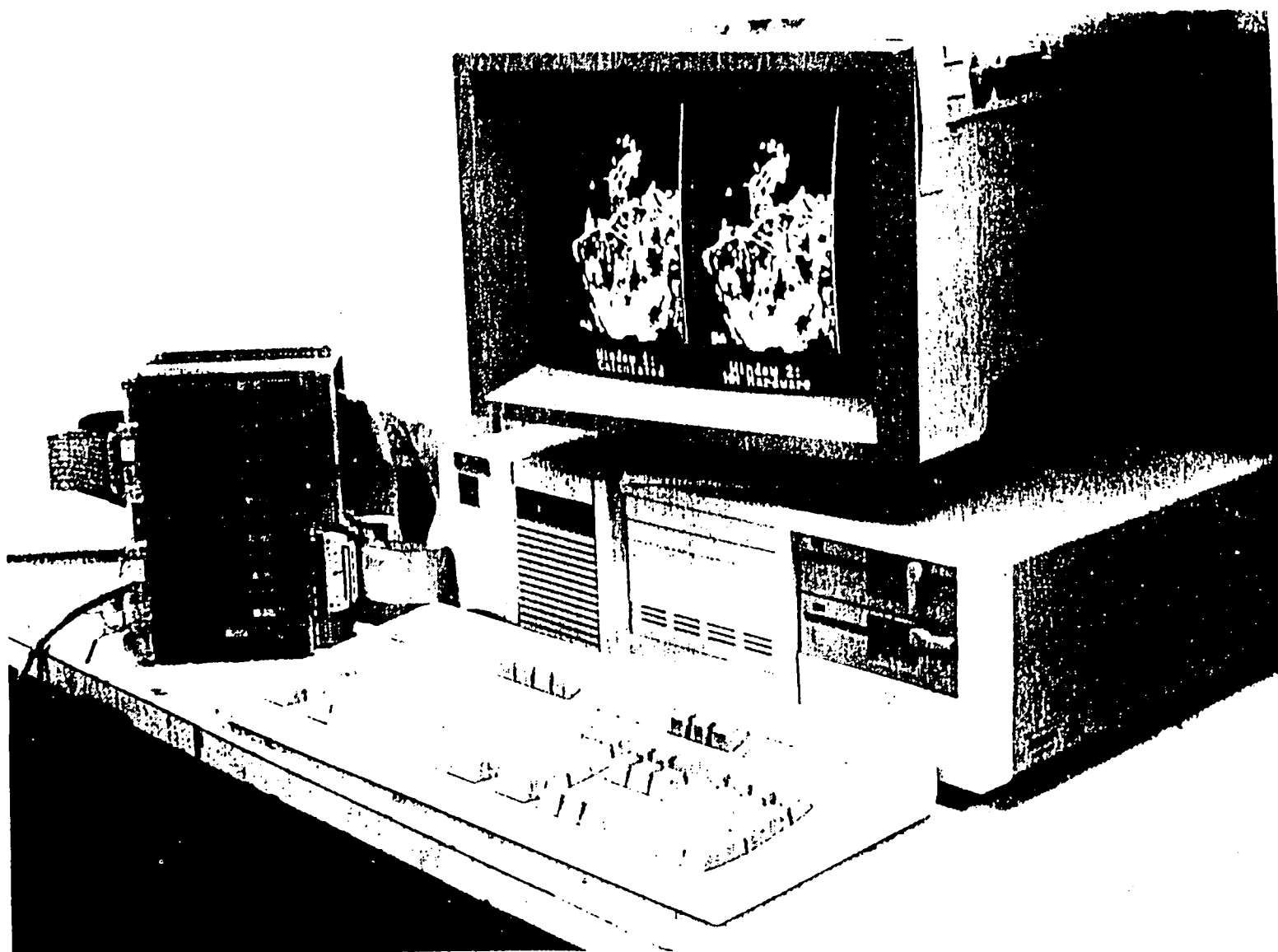
A DEDICATED PROCESSOR FOR PATH PLANNING

- MASSIVELY PARALLEL, ANALOG, ASYNCHRONOUS PROCESSING

- ACCEPTABLE SOLUTION IN REAL TIME, THAN THE BEST SOLUTION AFTER A LONG TIME

- ORDERS OF MAGNITUDE SPEED IMPROVEMENT, PARTICULARLY FOR "WHAT IF" EXPERIMENTS

PATH COMPUTATION
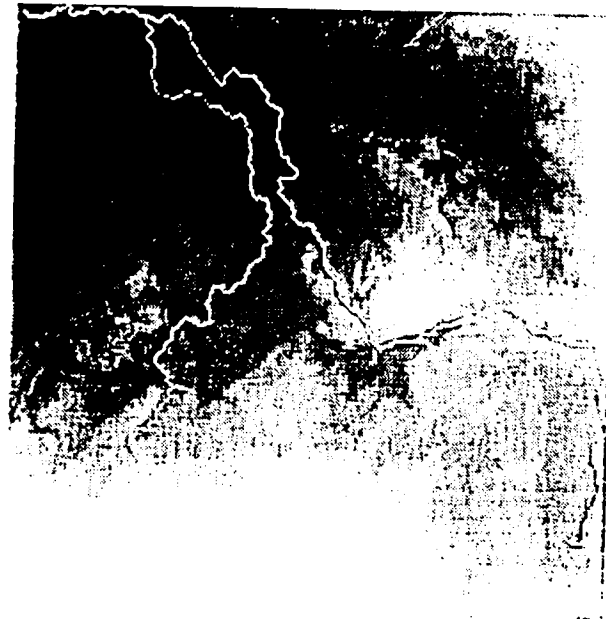
HARDWARE DETAIL FOR SIGNAL SORTER
AND MAP SEPARATES APPLICATIONS

I/O BUS

DOWNLOAD INTERFACE

MUX INPUT NEURON 64-CH

32 x 32 SYNAPSE CHIP

32 x 32 SYNAPSE CHIP

DOWNLOAD INTERFACE

MUX INPUT NEURON 64-CH

32 x 32 SYNAPSE CHIP

32 x 32 SYNAPSE CHIP

DOWNLOAD INTERFACE

MUX INPUT NEURON 64-CH

32 x 32 SYNAPSE CHIP

32 x 32 SYNAPSE CHIP

DOWNLOAD INTERFACES

32 NEURON CHIP

32 x 32 SYNAPSE CHIP

32 NEURON CHIP

DOWNLOAD INTERFACE

A/D BOARD

SIGNAL SORTER 128-1024 INPUT UNITS

MAP SEPARATES 64-256 INPUT UNITS

JPL NEURAL NETWORK SYSTEM INTERFACE

157

DIRECT INPUT

DIRECT OUTPUT

ANALOG INPUTS

ANALOG OUTPUTS

NEURAL NETWORK SUBSYSTEM

1 MByte/sec

DATA RATE

SCSI CONTROLLER

HOST COMPUTER

SCSI CONTROLLER

DOWNLOAD INTERFACE

FOR PROGRAM-MING INPUT VALUES

DOWNLOAD   INTERFACES

FOR PROGRAMMING WEIGHTS

A/D CONVERTER

I/O BUS   (DIGITAL)
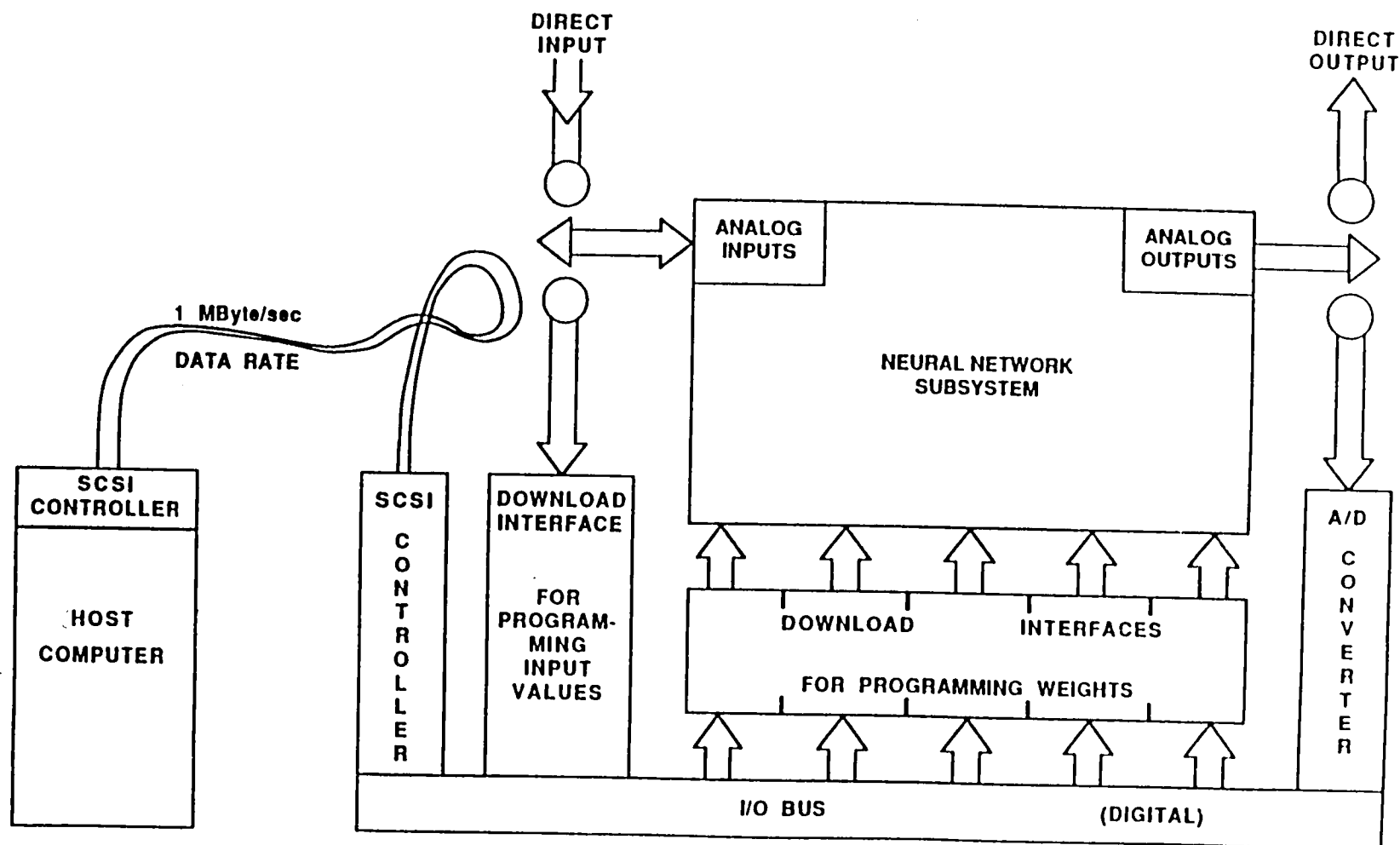
ELECTRONIC NEURAL NETWORKS
RAPID HARDWARE PROTOTYPING OF NEURAL PROCESSORS FOR "REAL" PROBLEMS

THE PROBLEMS

- MAP KNOWLEDGE BASE APPLICATIONS REQUIRING LARGE AMOUNTS OF DATA AND HIGH SPEED PROCESSING

  - CROSS-COUNTRY MOBILITY DETERMINATION: A MULTIDIMEN-SIONAL EUCLIDEAN DISTANCE MINIMIZATION PROBLEM

  - GENERATION OF MAP SEPARATES: AN IMAGE SEGMENTATION PROBLEM

  - DETERMINATION OF "BEST" PATH: A ROUTING PROBLEM

THE SOLUTION

- DEDICATED NEUROPROCESSORS IMPLEMENTING NEURAL ALGORITHMS FOR SOLVING THESE PROBLEMS

- THESE NEUROPROCESSORS WILL BE INTERFACED WITH A PORTABLE ASAS WORK STATION (PAWS) FOR USER EVALUATION AT THE CENTER FOR SIGNALS WARFARE (CSW)

JPL NEURAL NETS FOR ROBOTIC CONTROL

LAYERED, FEED-FORWARD NETS WITH ABILITIES TO 'LEARN' FROM 'EXPERIENCE'

159
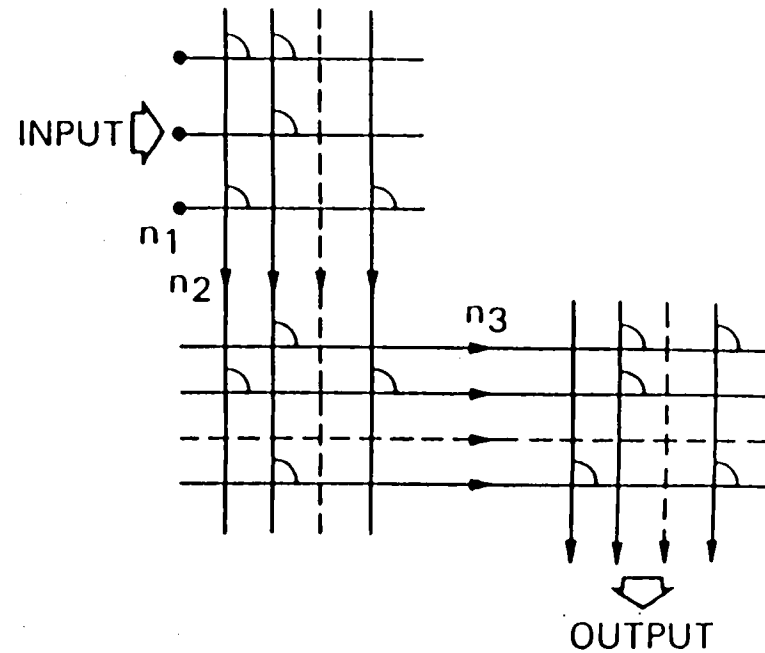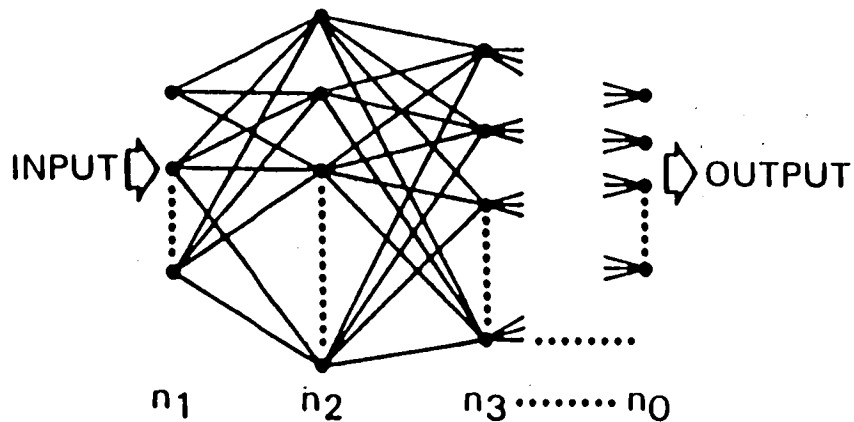
- LEARNING ALGORITHM: ERROR BACK PROPAGATION

- 'KNOWLEDGE' IS ACCUMULATED IN THE ANALOG SYNAPTIC WEIGHTS

ERROR BACKPROPAGATION ALGORITHM
FOR LEARNING

RANDOMIZE SYNAPTIC WEIGHTS

↓

FEED INPUT

↓

FORWARD PASS

↓

TRAINING SET

COMPARE OUTPUT WITH
DESIRED TARGET

↓

GENERATE ERROR VECTOR

↓

IS LEARNING COMPLETE?

↓

ADJUST WEIGHTS

$\Delta w_{ij} = \eta \delta_i o_j$

↑

YES ← ERROR < TOLERANCE → NO

↓

STORE WEIGHTS
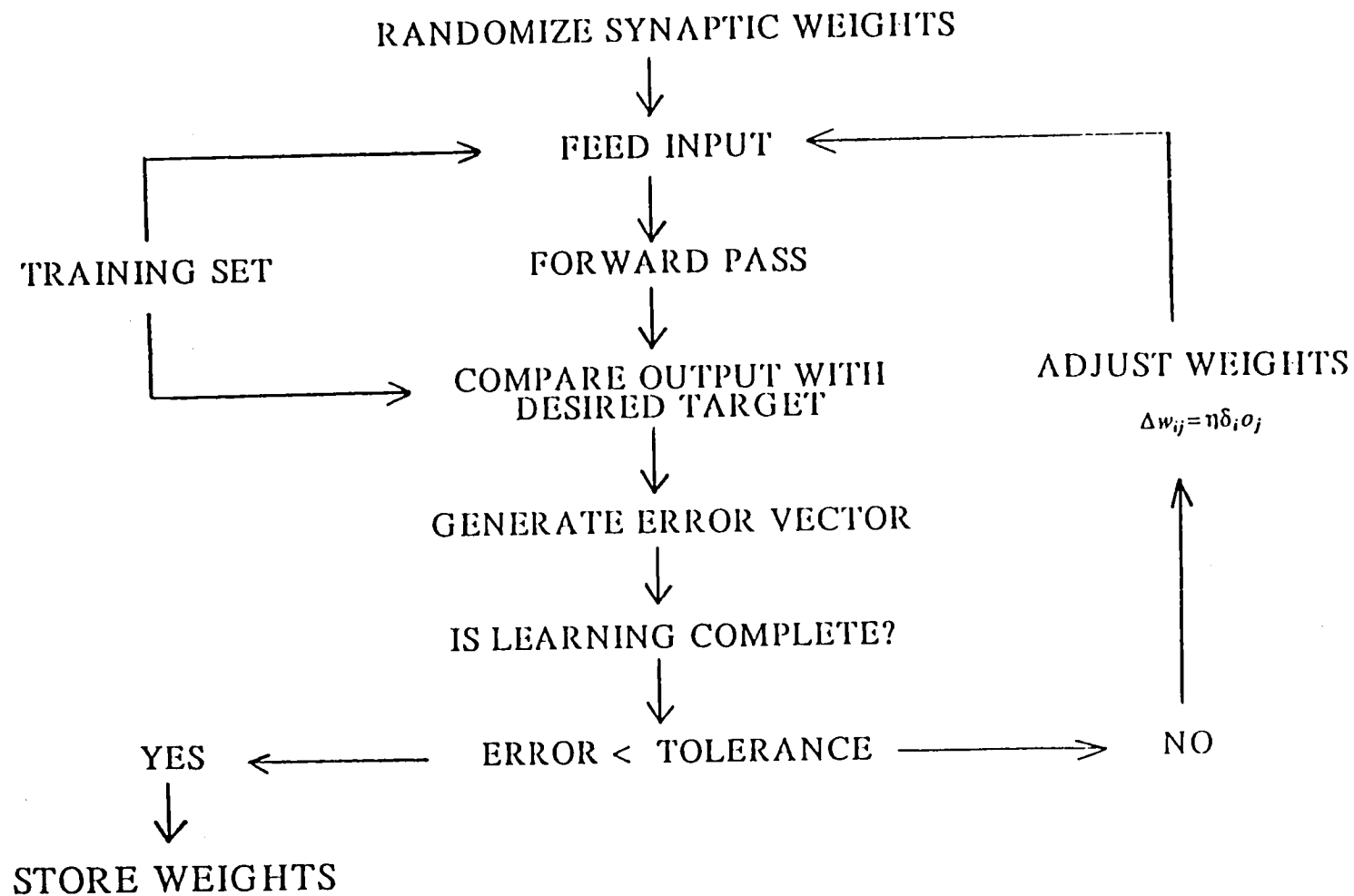
JPL RESOURCE ALLOCATION MATRIX

TARGET
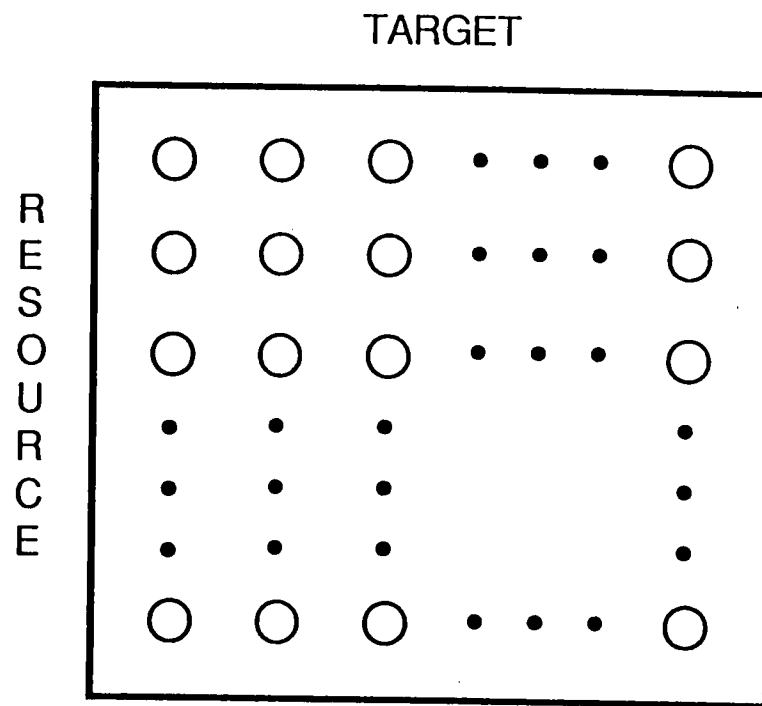
RESOURCE

RESOURCE ALLOCATION PROCESSOR SIMULATION

JPL

01/01	01/01	01/02	01/01	01/04	01/01	
2	9	4	4	3	2	01/02
1	9	9	2	3	9	01/01
5	6	4	3	4	2	01/03
8	6	8	4	5	3	01/01
3	4	5	1	9	9	01/02
9	2	3	5	9	9	01/01
	08/10					
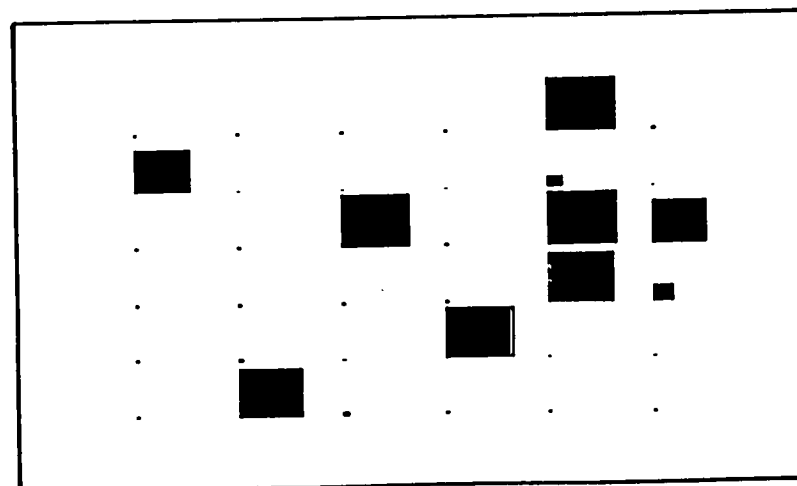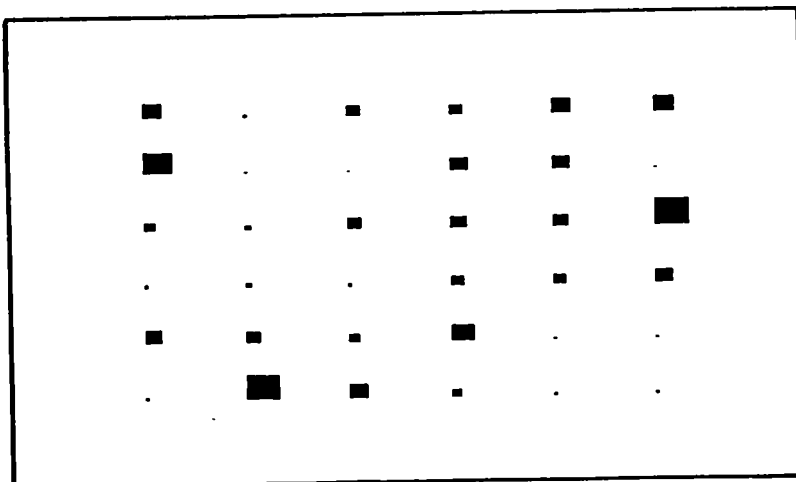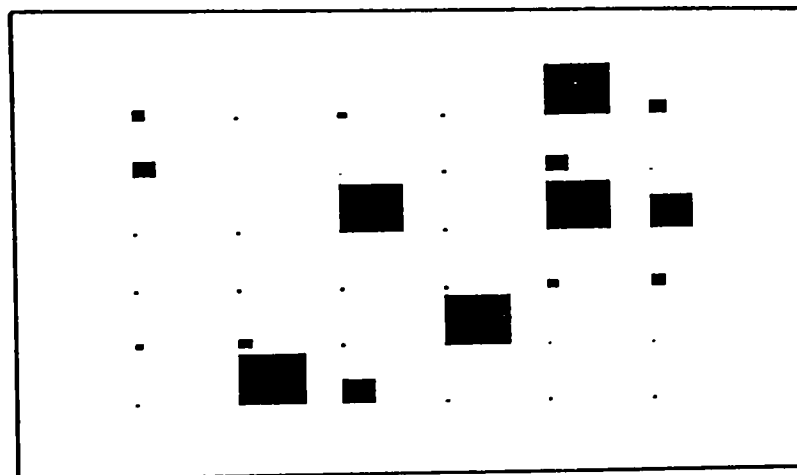
GLOBAL OPTIMIZATION NEUROPROCESSOR

- RESOURCE ALLOCATION
- DYNAMIC ASSIGNMENT
- MESSAGE ROUTING
- TARGET-WEAPON PAIRING
- LOAD BALANCING
- MULTI-TARGET TRACKING
- SEQUENCING / SCHEDULING
- REAL TIME, ADAPTIVE
  MISSION RE-PLANNING
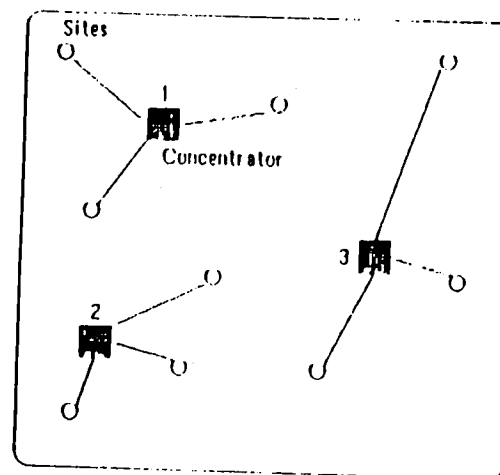
Sites

Concentrator

NINE SITES
3 CONCENTRATORS

ALLOT 3 SITES TO EACH
CONCENTRATOR TO ACHIEVE
MINIMUM OVERALL COST

•• NEUROPROCESSING APPROACH OFFERS OVER 4 ORDERS OF MAGNITUDE SPEED ENHANCEMENT OVER THE CONVENTIONAL COMPUTING TECHNIQUES.

•• ARBITRARY MULTIPLE TO MULTIPLE ASSIGNMENTS ARE POSSIBLE, WHICH ARE NOT EASILY ACCOMPLISHED BY CONVENTIONAL TECHNIQUES.

163

ELECTRONIC NEURAL NETWORKS

JET PROPULSION LABORATORY

PROGRAMMABLE, NONVOLATILE, HIGH-DENSITY, THIN FILM SYNAPTIC ARRAY FOR INFORMATION STORAGE

10 μm
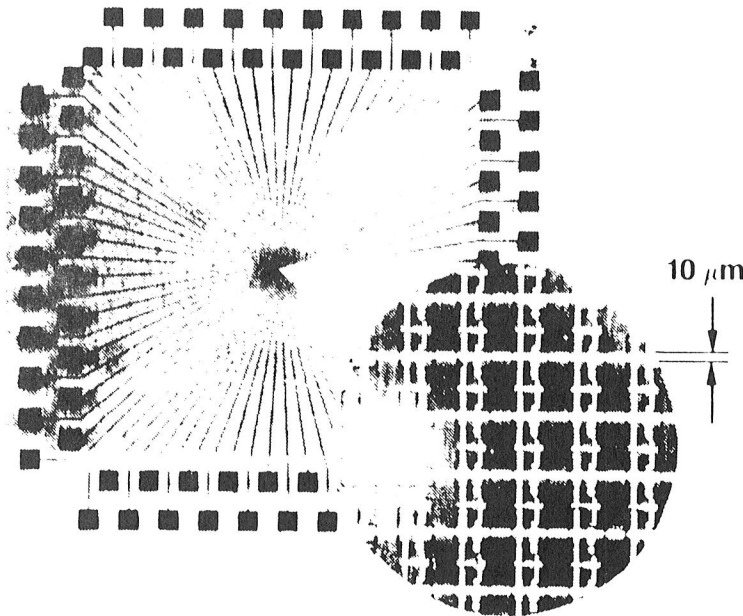
- POTENTIAL FOR HIGH DENSITY APPROACHING 10^9 BITS/CM^2

- FAULT-TOLERANCE

- ASSOCIATIVE, CONTENT-ADDRESSABLE RECALL

- NO MOVING PARTS

- STORAGE IN "PASSIVE," RAD-HARD INTERCONNECTIONS

ELECTRICALLY PROGRAMMABLE
READ ONLY THIN-FILM SYNAPTIC ARRAY
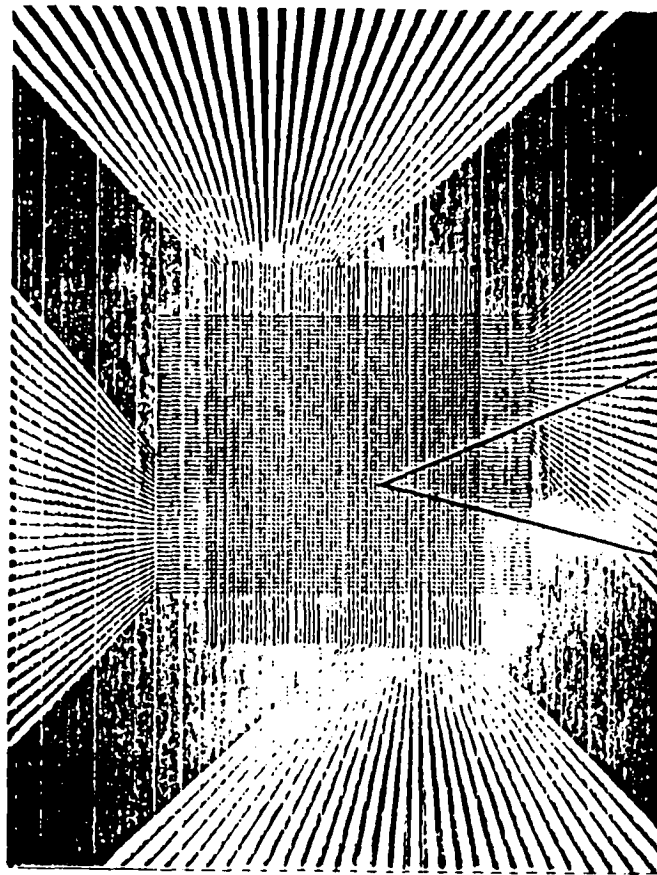
A 62 x 62 SYNAPSE TEST ARRAY WITH
4-μm FEATURE SIZE

4 μm
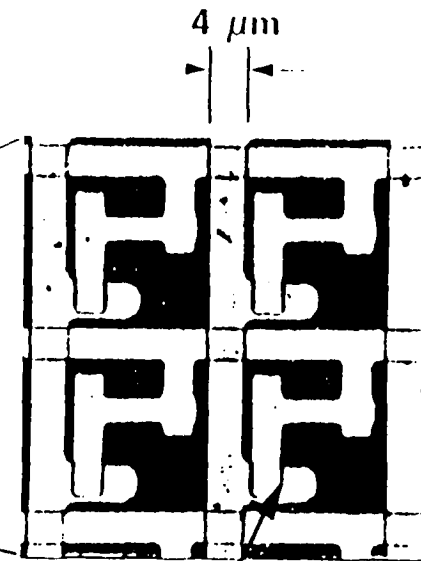
a-Si:H MICROSWITCH
AND RESISTOR SANDWICHED
BETWEEN METAL ELECTRODES

CONCLUSIONS

- THE FIELD OF NEUROPROCESSING HAS SIGNIFICANTLY ADVANCED IN RECENT YEARS. INVESTMENTS OF DOD AND NASA ARE RESULTING IN THE DEVELOPMENT OF APPLICATION-SPECIFIC, HIGH PERFORMANCE, MODULAR NEUROPROCESSORS.

- SUCH NEUROPROCESSORS OFFER TOTALLY NEW CAPABILITIES, COMPUTATIONAL BREAKTHROUGHS, AND ORDERS OF MAGNITUDE PERFORMANCE ENHANCEMENT WHERE CONVENTIONAL PROCESSING METHODS CHOKE.

- DOD IS MOVING AHEAD IN THE DIRECTION OF HARDWARE PROTOTYPING OF DEPLOYABLE NEUROPROCESSORS FOR COMPLEX PROBLEMS IN BATTLEFIELD MANAGEMENT AND TACTICAL FUSION OF INTELLIGENCE, ETC.

- *TIME IS RIGHT FOR NASA TO TAKE ADVANTAGE OF THIS POWERFUL TECHNOLOGY. TAILORED NEUROPROCESSORS WILL BE IDEALLY SUITED TO SATISFY NASA'S UNIQUE AND GROWING DEMANDS IN COMPUTATION AND DATA MANAGEMENT WITH THE EVOLUTIONARY DEVELOPMENT OF SPACE STATION.*

166

TECHNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP	SYSTEMS DEVELOPMENT & SIMULATION DIVISION	
DATA MANAGEMENT SYSTEM	EF2/G. C. BLACKBURN	JANUARY 1990

SPACE STATION DISPLAYS AND CONTROLS TECHNOLOGY EVOLUTION

GREG C. BLACKBURN
SYSTEMS DEVELOPMENT MANAGER
FOR
SPACE STATION DMS DISPLAYS & CONTROLS
(713) 483-1517

N93-28712

163600

5a-18

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DATA MANAGEMENT SYSTEM SPACE STATION DISPLAYS & CONTROLS TECHNOLOGY EVOLUTION	EF2/G. C. BLACKBURN	JANUARY 1990

- **A HISTORICAL PERSPECTIVE**

- **MAJOR DEVELOPMENT OBJECTIVES**

- **CURRENT DEVELOPMENT ACTIVITIES**

- **KEY TECHNOLOGY AREAS**

- **TECHNOLOGY EVOLUTION ISSUES**

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169

- A HISTORICAL PERSPECTIVE

    - DEDICATED DISPLAYS & CONTROLS (D&C) IN PAST PROGRAMS

        - ORBITER HAS OVER 1,200 DEDICATED SWITCHES

        - MULTIFUNCTIONAL D&C HAS BEEN LIMITED

    - LIMITED ONBOARD DATA PROCESSING

    - MUCH OF DATA RECORDED OR TELEMETERED TO THE GROUND FOR PROCESSING

    - EXTENSIVE GROUND MONITORING OF ALL SYSTEMS

    - OPTIMIZATION OF PROGRAM OBJECTIVES

        - CREW INTERFACE CONSIDERED SECONDARY

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- MAJOR DEVELOPMENT OBJECTIVES

    - LOWER COSTS, IMPROVE MAINTENANCE/RELIABILITY

    - MINIMIZE PARTS/SKILL OBSOLENCE

    - MINIMIZE POWER, WEIGHT, VOLUME CONSUMPTION

    - PROVIDE A DESIGN WHICH ALLOWS FOR INFUSION OF NEW TECHNOLOGY

    - REDUCE CREW'S OVERALL WORKLOAD

    - MAXIMIZE FLIGHT SAFETY AND CREW EFFICIENCY

    - PROVIDE A SOFTWARE RECONFIGURABLE INTERFACE

    - MINIMIZE THE USE OF PAPER ON-ORBIT

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- CURRENT DEVELOPMENT ACTIVITIES

  - DISTRIBUTED SYSTEM ARCHITECTURE

  - CREW COMMAND AND CONTROL INTERFACE VIA MULTIPURPOSE WORKSTATIONS

    - MULTIPLE MULTIFUNCTION DISPLAY DEVICES

    - KEYBOARD

    - CURSOR CONTROL DEVICE

    - PROGRAMMABLE SWITCHES

    - HAND CONTROLLERS

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DATA MANAGEMENT SYSTEM SPACE STATION DISPLAYS & CONTROLS TECHNOLOGY EVOLUTION	EF2/G. C. BLACKBURN	JANUARY 1990

- **KEY TECHNOLOGY AREAS**

  - **COLOR FLAT PANEL TECHNOLOGY**

    - **COLOR ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS**

    - **LARGE COLOR PLASMA DISPLAYS**

  - **ADVANCED PROCESSORS**

    - **LATER GENERATION GENERAL PURPOSE PROCESSORS**

    - **ADVANCED GRAPHICS PROCESSORS**

    - **HIGHER DENSITY MEMORIES**

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- **KEY TECHNOLOGY AREAS (CONTINUED)**
  - **NEW AND IMPROVED CREW I/O DEVICES**
    - **VOICE RECOGNITION**
    - **VOICE SYNTHESIS**
    - **ADVANCED CURSOR CONTROL**
  - **ADVANCED MANIPULATOR/ROBOTIC CONTROL**
    - **HAND CONTROLLER TECHNOLOGY**
  - **IMPROVED CREW INTERFACE SOFTWARE**
    - **NEW CREW INTERFACE TECHNIQUES**
    - **USE OF AI/EXPERT SYSTEMS**

TECNNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP	SYSTEMS DEVELOPMENT & SIMULATION DIVISION	
DATA MANAGEMENT SYSTEM SPACE STATION DISPLAYS & CONTROLS TECHNOLOGY EVOLUTION	EF2/G. C. BLACKBURN	JANUARY 1990

- • TECHNOLOGY EVOLUTION ISSUES

  - MATURITY OF COLOR FLAT PANEL TECHNOLOGY

  - NO SPACEFLIGHT EXPERIENCE WITH ADVANCED INTERACTIVE MULTIPURPOSE SOFTWARE SYSTEMS

    - DEFINITION OF DISPLAY FORMATS

    - DEFINITION OF GRAPHIC OBJECTS

    - EFFICIENT NAVIGATION THROUGH A HIGH NUMBER OF DIFFERENT FORMATS

    - ELIMINATION OF DEDICATED SYSTEM D&C PANELS

174

Johnson Space Center-Houston, Texas

TECNNOLOGY FOR SPACE STATION EVOLUTION - A WORKSHOP	SYSTEMS DEVELOPMENT & SIMULATION DIVISION	
DATA MANAGEMENT SYSTEM SPACE STATION DISPLAYS & CONTROLS TECHNOLOGY EVOLUTION	EF2/G. C. BLACKBURN	JANUARY 1990

- **TECHNOLOGY EVOLUTION ISSUES (CONTINUED)**

  - **MATURITY AND UTILIZATION OF AI/EXPERT SYSTEM TECHNOLOGY IN A SPACECRAFT**

  - **CREW ACCEPTANCE OF A WORKSTATION INPUT VIA VOICE COMMAND**

  - **DANGER OF MAKING CREW BORED (MACHINE MINDERS)**

  - **LATER INCORPORATION OF NEW TECHNOLOGY**

    - **DIFFICULTY IN UPGRADING AN EXISTING OPERATIONAL NASA SPACECRAFT**

    - **ON-ORBIT CHECK-OUT/VERIFICATION**

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EMBEDDED MULTIPROCESSOR TECHNOLOGY FOR VHSIC INSERTION

Presented at
Technology for Space Station Evolution
– A Workshop

January 16-19, 1990

Paul J. Hayes
NASA Langley Research Center
(804) 864-1491

N93-27713
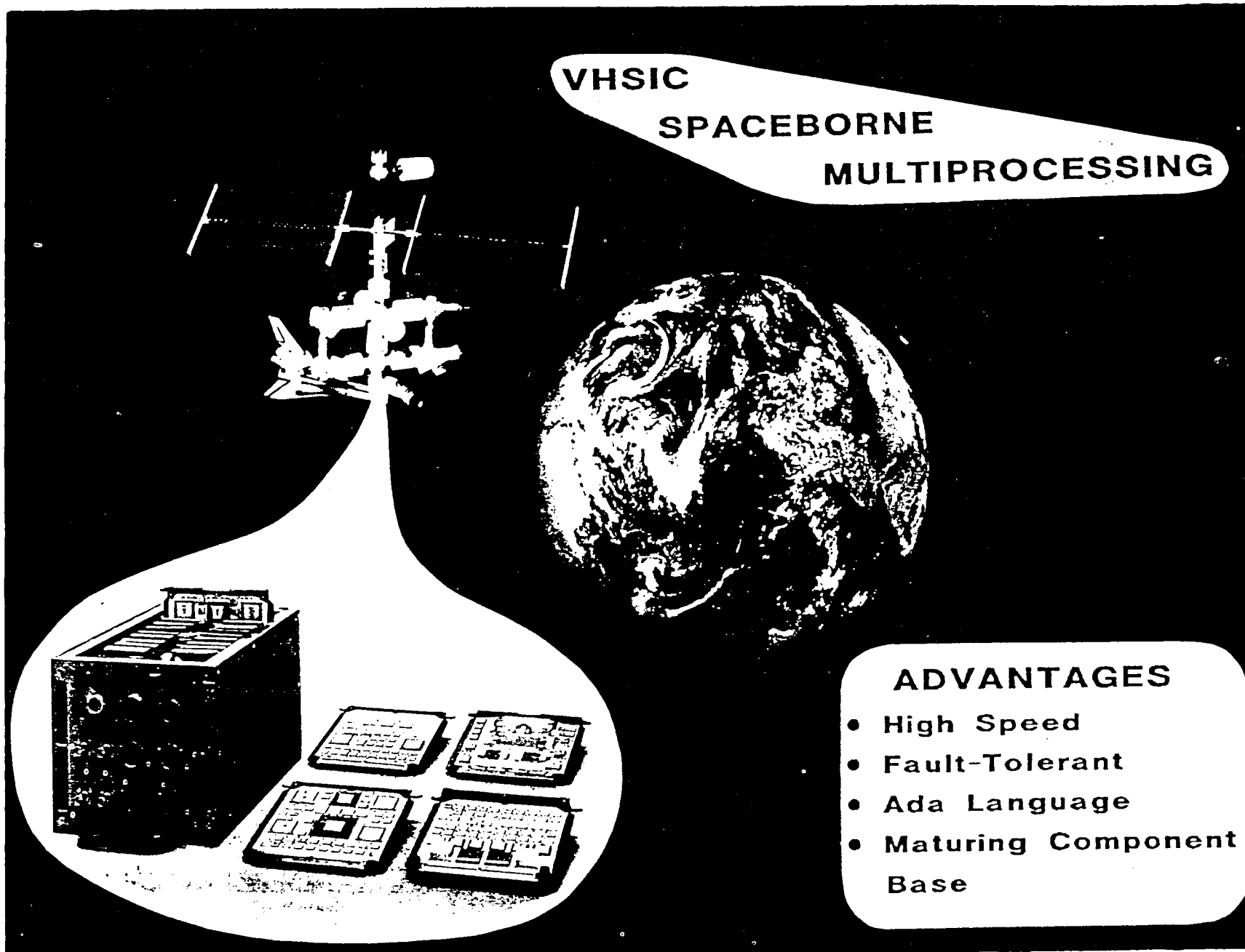
NASA MULTIPROCESSOR TECHNOLOGY

OBJECTIVE

Develop multiprocessor system technology providing user-selectable fault tolerance, increased throughput, and ease of application representation for concurrent operation.

APPROACH

Develop graph management mapping theory for proper performance, model multiprocessor performance, and demonstrate performance in selected hardware systems.

MULTIPROCESSING TECHNOLOGY
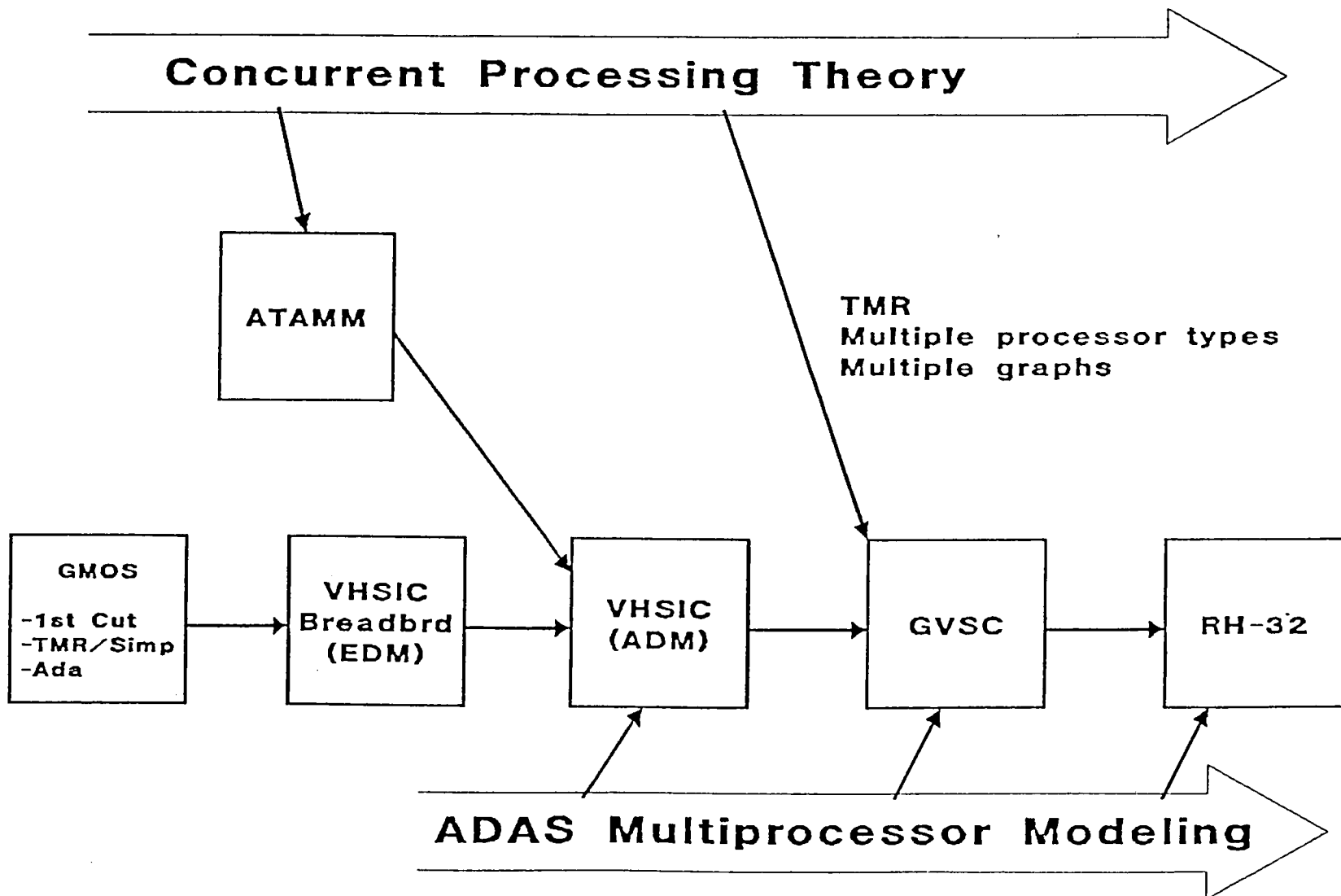
Graph Management Operating System
(GMOS)
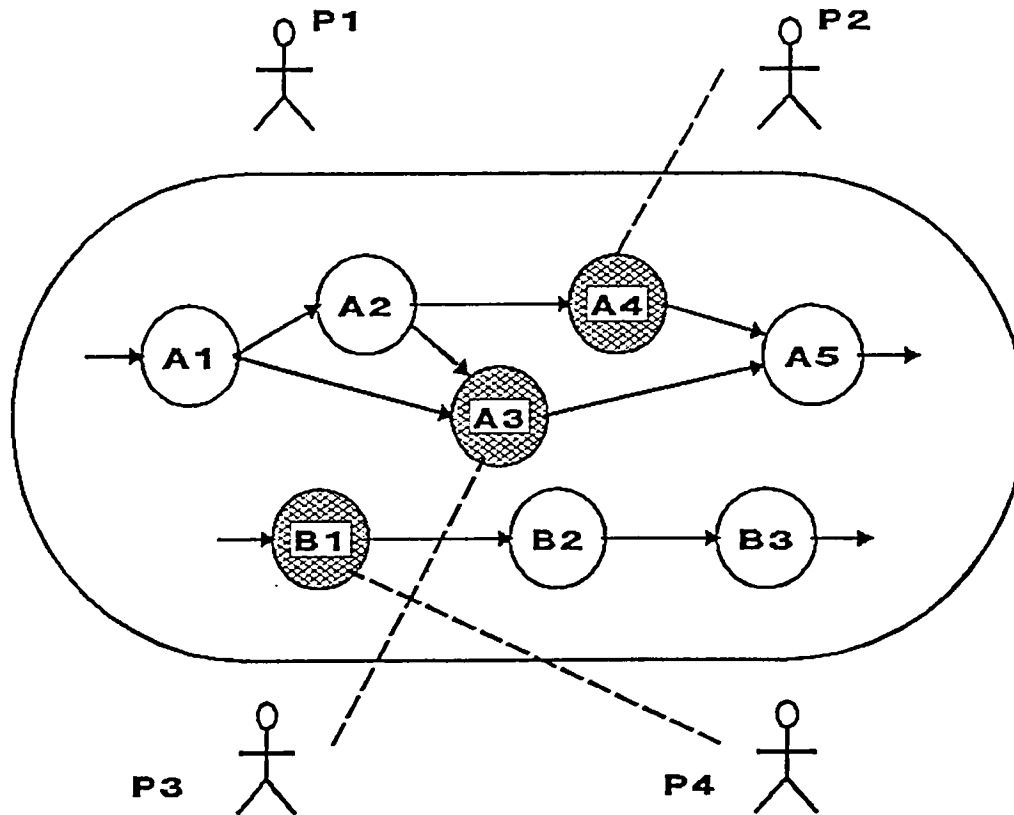
Processor Assignment for Node Execution

Features

o Distributed O/S
   and Nodes

o Real-Time Node
   Assignment

o Application Graph

o Node-Selectable
   Fault Tolerance

o Ada

o VHSIC 1750A

GMOS FUNCTIONAL FEATURES

- EXECUTES DIRECTED GRAPH – SINGLE GRAPH
  - MULTIPLE GRAPH

- GRAPH NODE CRITICALITY – TMR OR SIMPLEX

- GRAPH NODE SCHEDULING

  A) DATA DRIVEN – EVENT FLAG
    - SEMAPHORE (MULTIPLE EVENTS)
    - AND/OR LOGIC

  B) DEMAND DRIVEN – PERIODIC TIMER
    - ONE-SHOT TIMER

- BACKUP NODE ALLOCATION

- FAULTY PROCESSOR EXCLUSION, SELF TEST, REBOOT

ALGORITHM TO ARCHITECTURE MAPPING MODEL (ATAMM)

- A strategy for the real-time assignment of the nodes of a data-driven algorithm graph to parallel processors

- Based on Petri-Net marked graph theory

- Aimed at large-grain graph applications

- Provides:
  - deadlock-free performance
  - optimum time performance
  - operating system rules
  - performance prediction

ALGORITHM MARKED GRAPH (AMG)
FOR 7-NODE EXAMPLE GRAPH
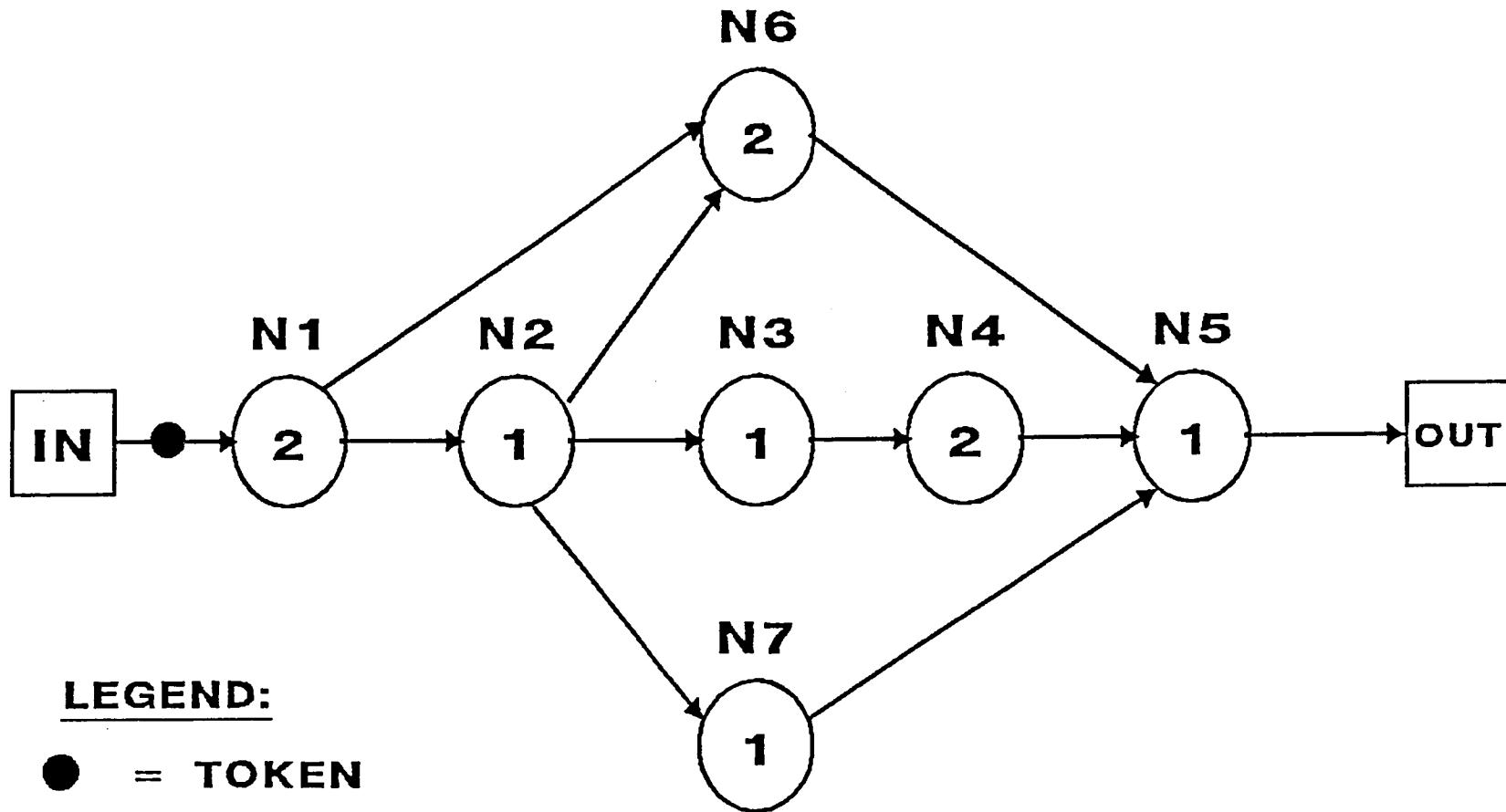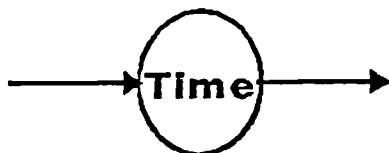
NODE MARKED GRAPH (NMG) FOR DATA HANDLING
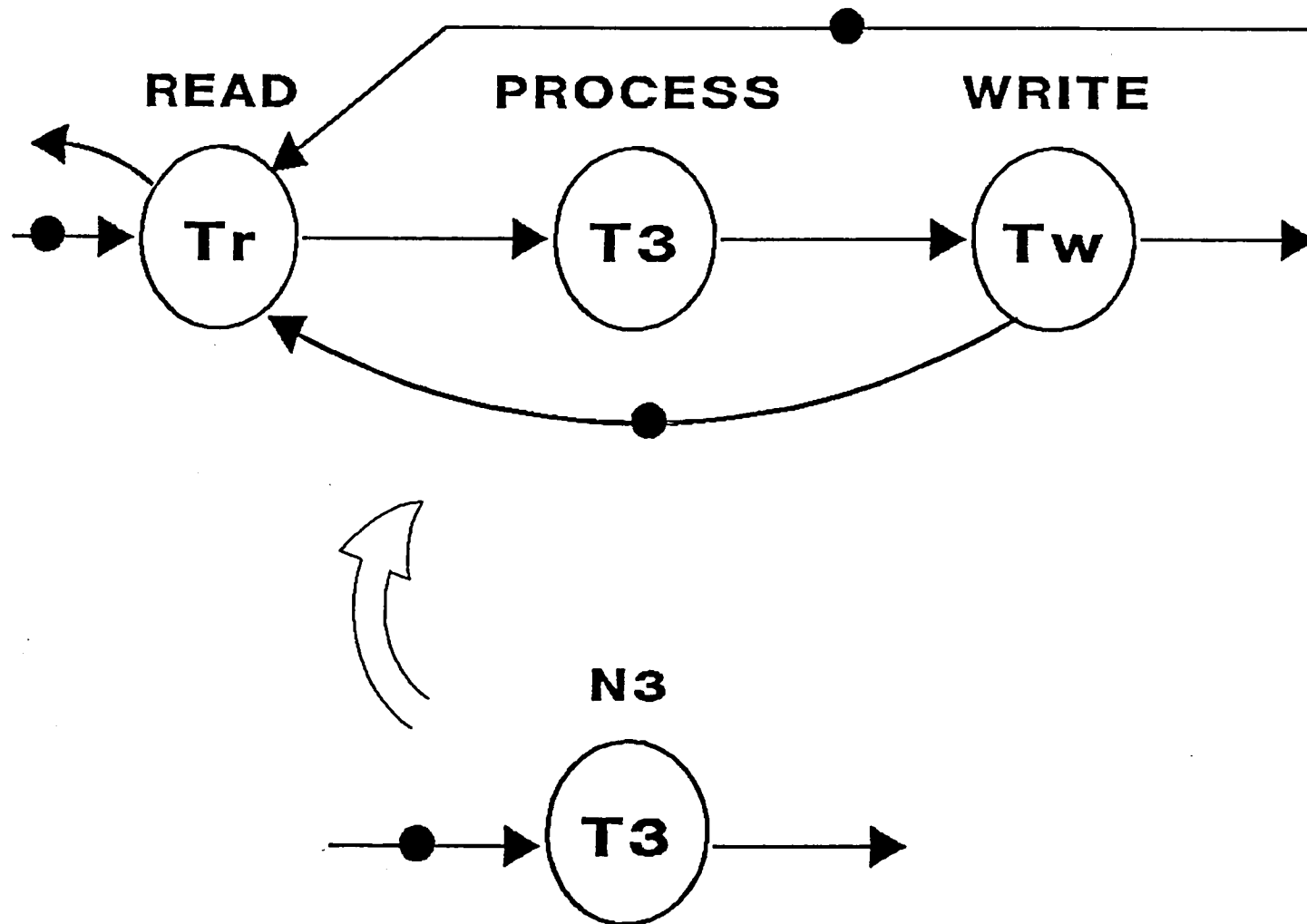
GRAPH FOR ANALYSIS
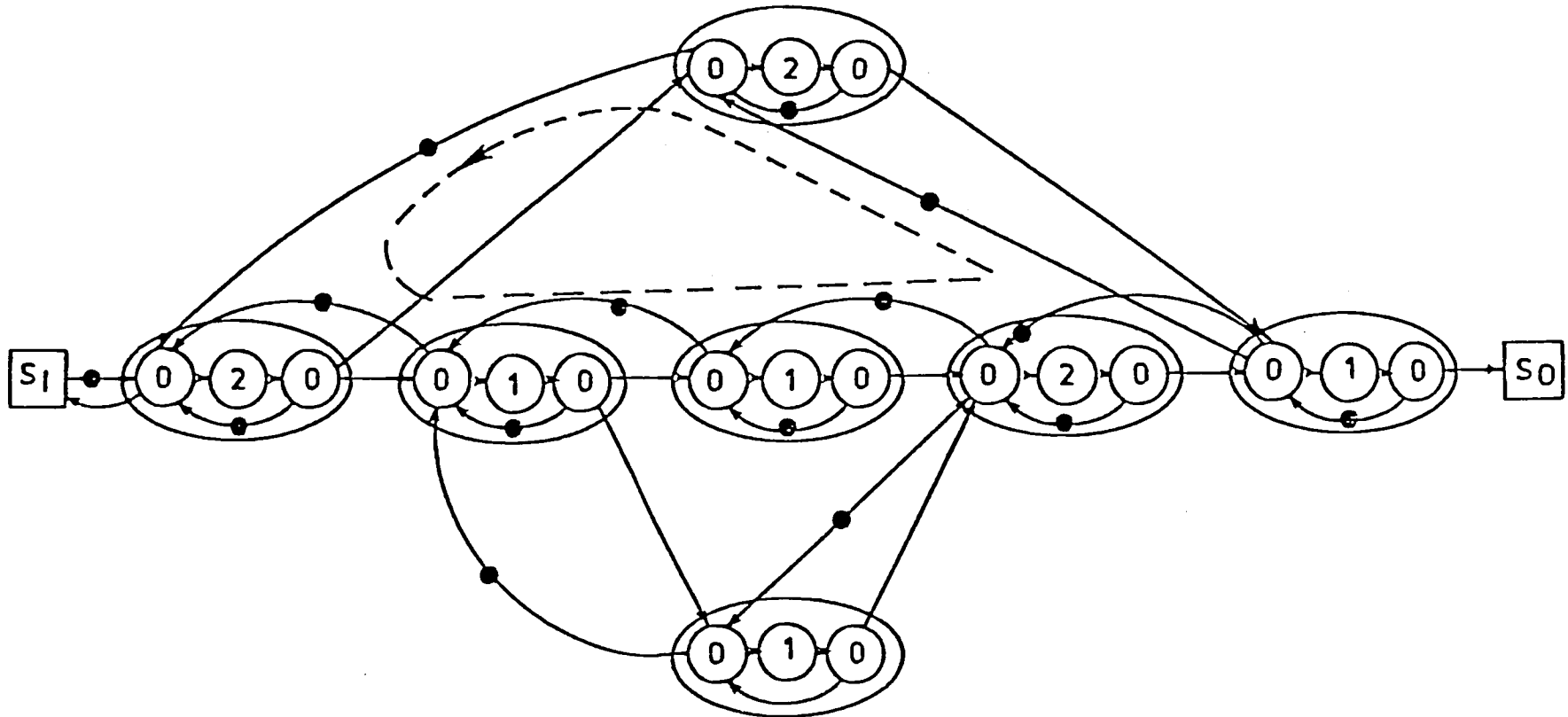
TBO $\equiv$ TIME BETWEEN SUCCESSIVE OUTPUTS

TBO$_M$ $\equiv$ MINIMUM VALUE FOR TBO

$\equiv$ MAX (TIME/NO. TOKENS)$_i$ $\equiv$ 6/2 $\equiv$ 3

PROCESSOR REQUIREMENT PLOT
(SEVEN PROCESSORS AVAILABLE)

* COMPLETION OF A NODE
■ COMPLETION OF NODE N5

PROCESSOR REQUIREMENT PLOTS

A) ONE PROCESSOR AVAILABLE

- COMPLETION OF A NODE
- COMPLETION OF NODE NS

B) TWO PROCESSORS AVAILABLE

C) THREE PROCESSORS AVAILABLE

D) FOUR PROCESSORS AVAILABLE

E) FIVE PROCESSORS AVAILABLE

F) SEVEN PROCESSORS AVAILABLE
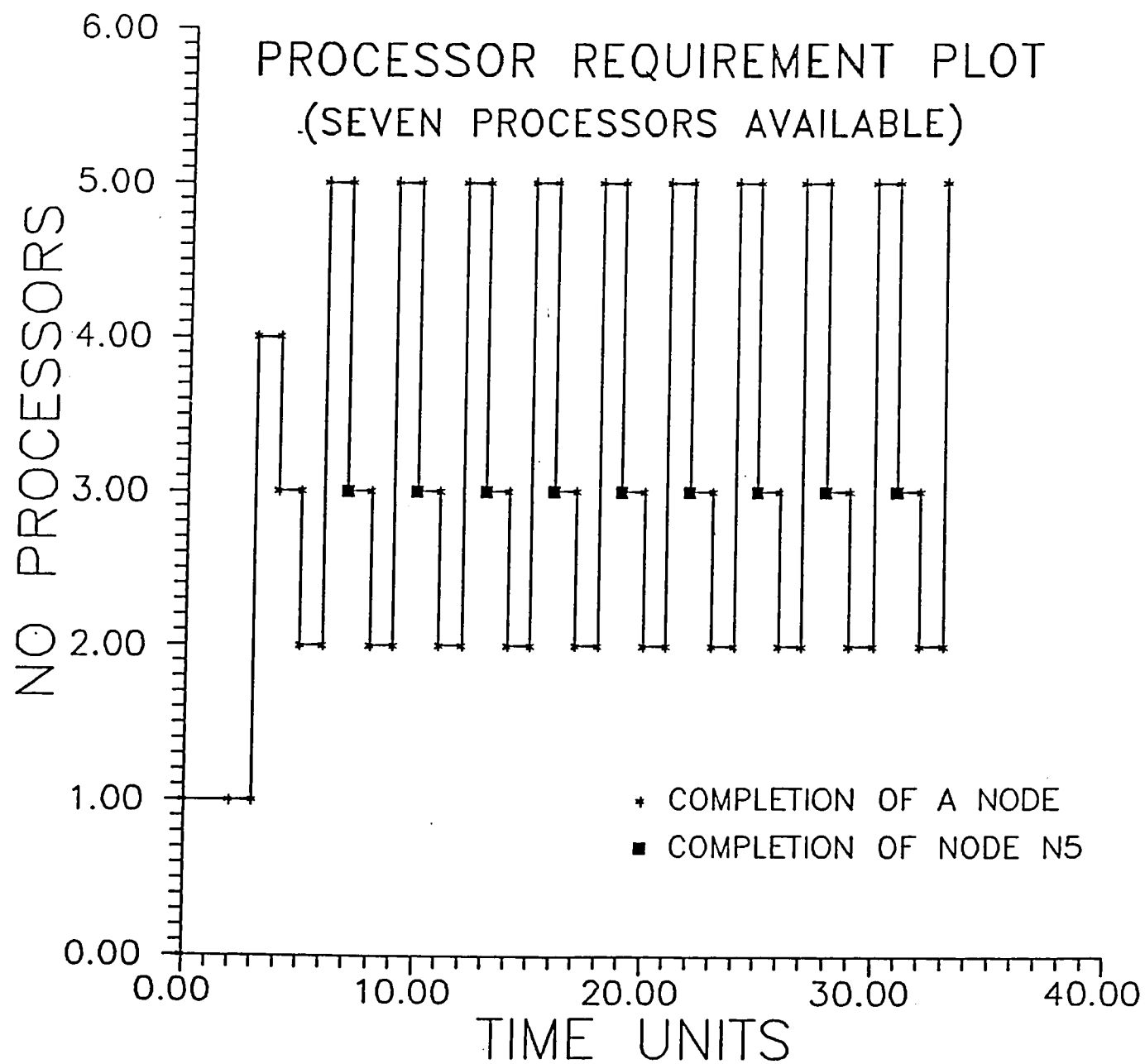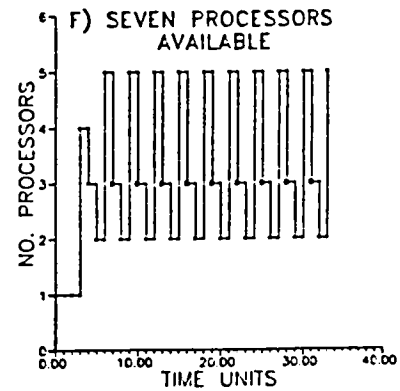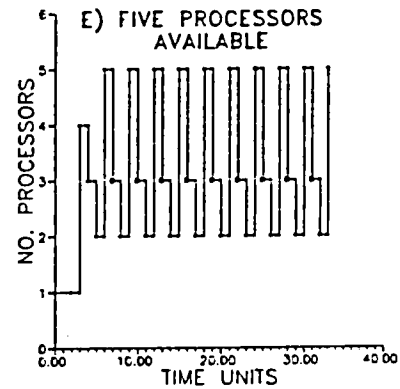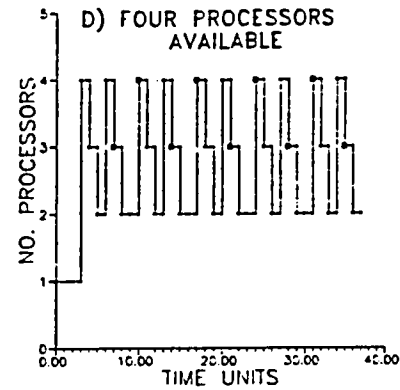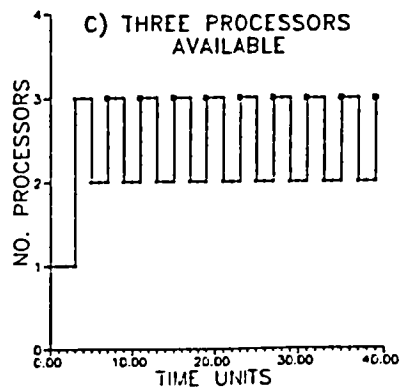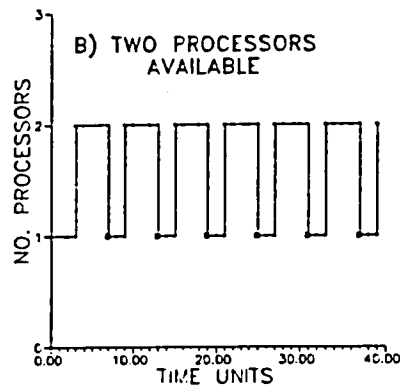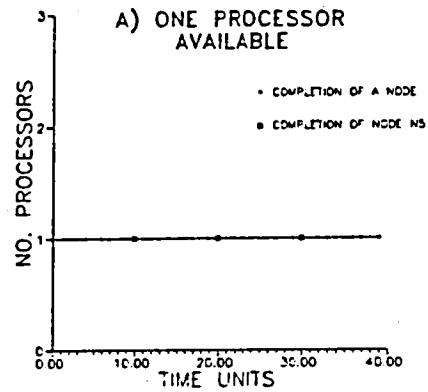
PERFORMANCE MARGIN
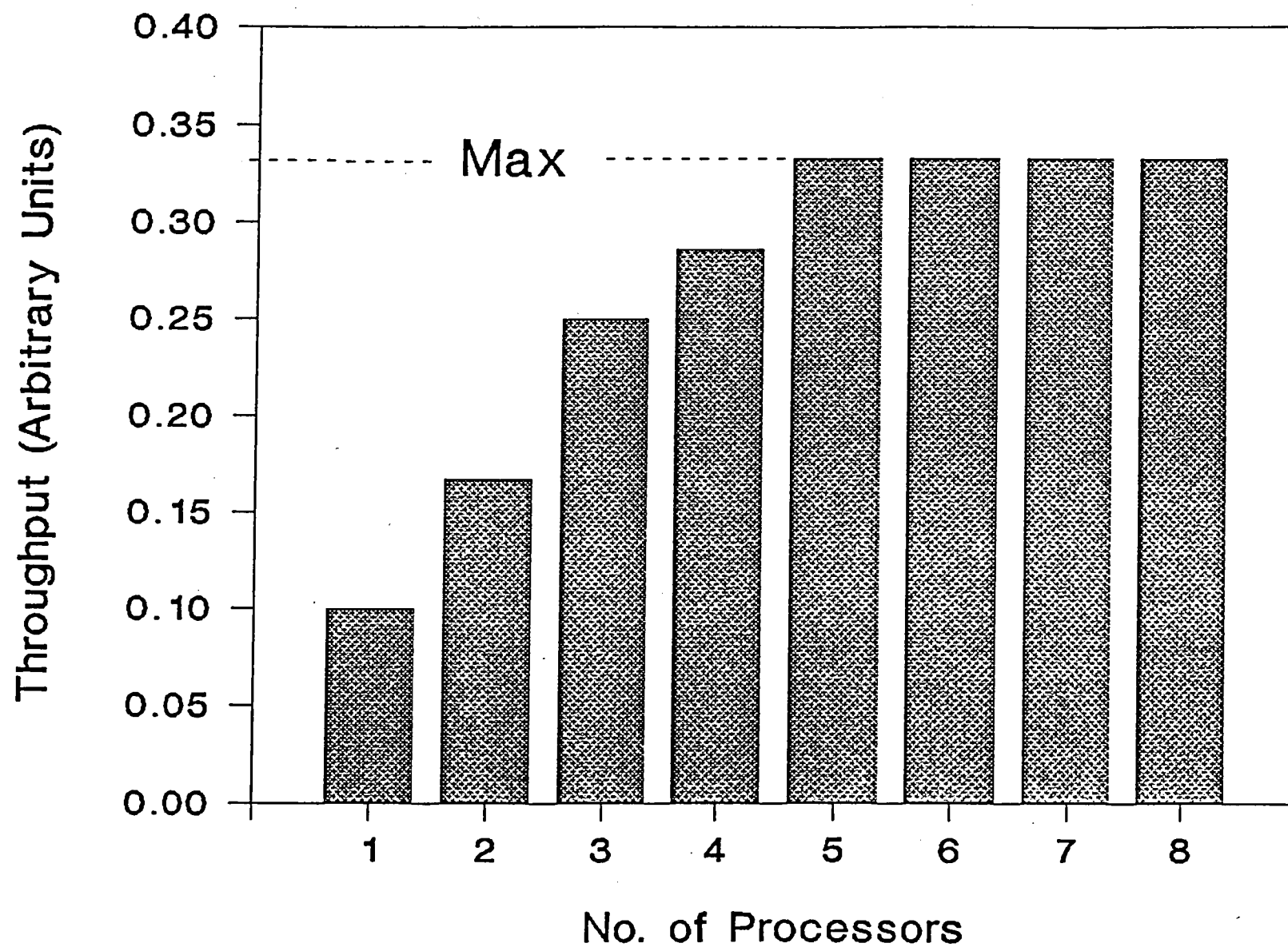
NORMALIZED THROUGHPUT
VERSUS
NUMBER OF PROCESSORS

NUMBER OF PROCESSORS
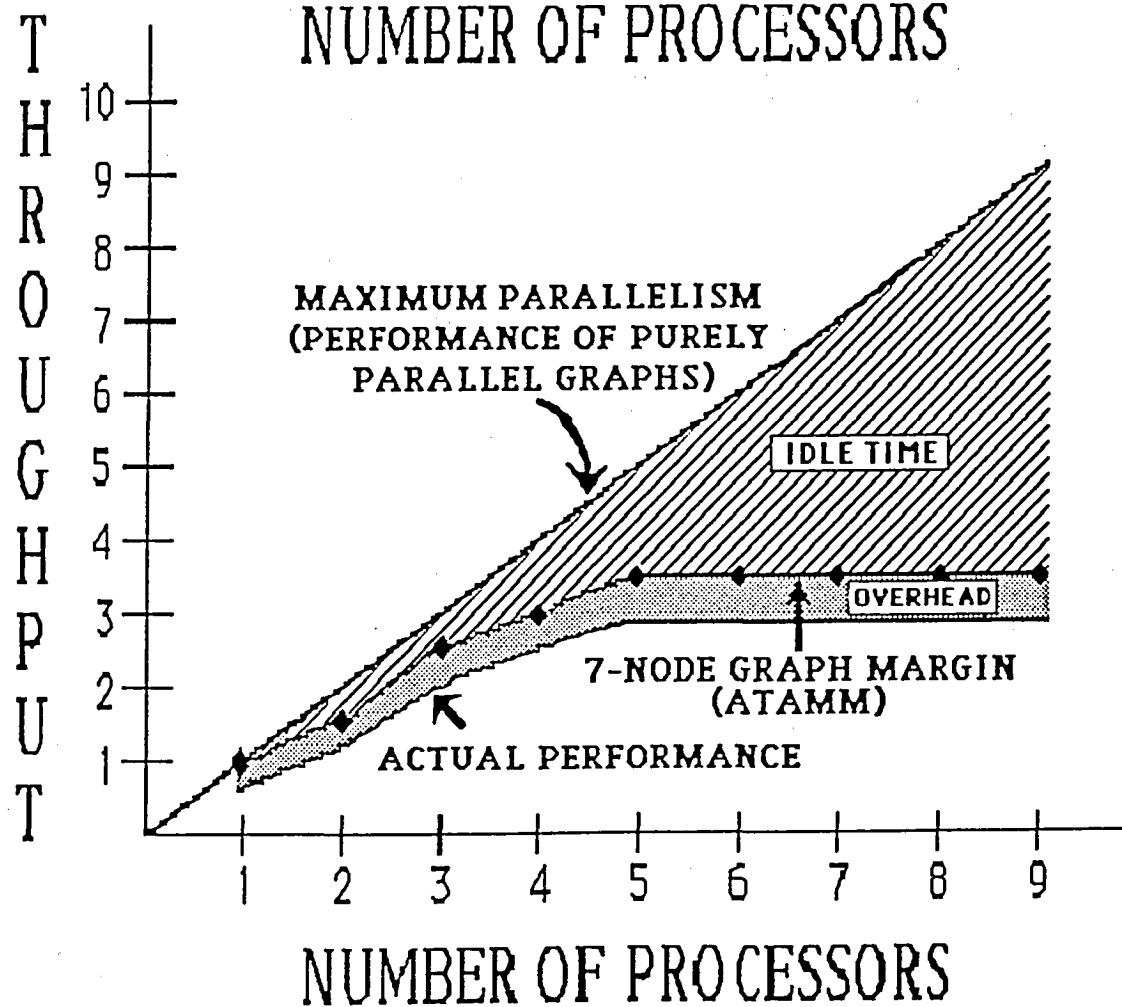
ATAMM PROVIDES A NEW CAPABILITY SET

o   Mathematically proven lock-free performance

o   Operating system rules to manage the
    assignment of graph nodes to processors

o   Prediction of graph's performance bounds
    - Maximum data rate
    - Maximum number of processors
    - Dependency of data rate on number
      of processors

ATAMM DEVELOPMENT/DEMO PLANS

STATUS	FEATURE	DEMO
Initial ATAMM	o Single graphs o Simplex o Identical processors (HW & SW)	ADM
Current Update	o Triple Modular Redundant (TMR) o Graph optimization for specific no. processors	
Future Features	o Multiple graphs o Multiple iterations of the same graph o Multiple processor types o Variable node-latency times	GVSC and/or RH-32

MAJOR RESEARCH THRUST FOR FY90

o   Implement ATAMM Rules into KOS

  - Simpler operating system than previous GMOS

  - Use Westinghouse Directed Graph Tool

  - Use 1553B to provide data I/O and
    monitor graph status

  - Improved version of Ada compiler

  - 2.5 MIPS VHSIC ADM 1750A processor

o   Demo/Evaluate with Ada Algorithms

  - Test Algorithm (Scan-to-scan track
    correlation for SDIO)

  - Time-simulated graphs

  - Simplex/TMR

  - Fault injection and continued processing

MULTIPROCESSOR INTERFACE DIAGRAM

194

**V1750A ADM
Chassis/Module**
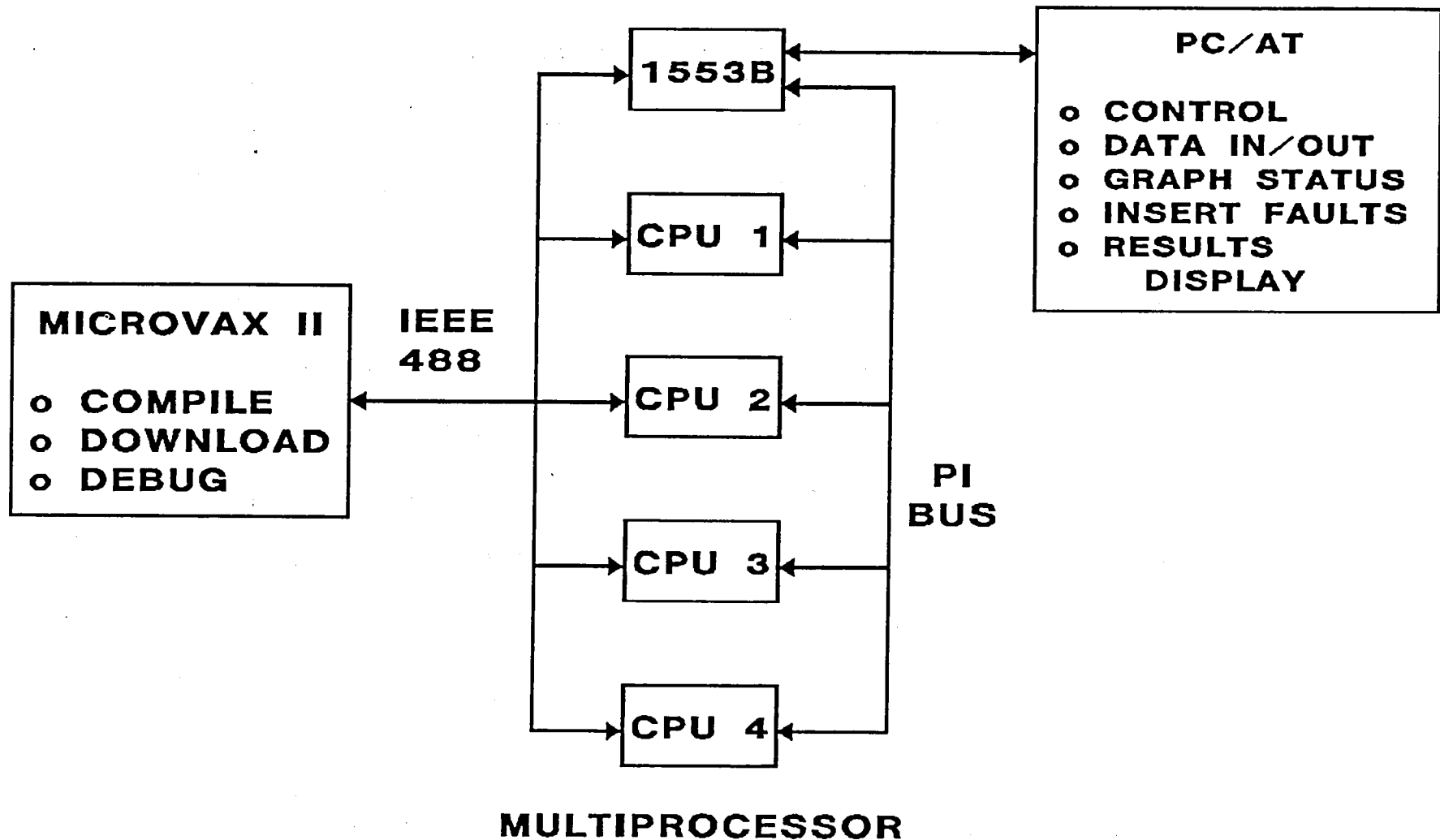
- 1.25μ CMOS VHSIC
- μ-Coded CPU Plus 256K RAM
- Surface-Mounted Devices; Dual Board Module
- 5.88 x 6.44 Inches (SEM-E)

MAJOR PROGRAM MILESTONES

FY

1) Integrate/Demo ATAMM and   90
SDIO Algorithm on Avionics
Advanced Development Model (ADM)

2) Adapt/Demo ATAMM-Based OS   91
on GVSC

3) Expand ATAMM Capability   94
and Adapt/Demo on RH-32

DATA MANAGEMENT STANDARDS IN COMPUTER-AIDED ACQUISITION AND LOGISTIC SUPPORT (CALS)

David K. Jefferson
National Institute of Standards and Technology
301-975-3262

Basic Thrusts of CALS

CALS is intended to reduce cost, increase quality, and improve timeliness of weapon system acquisition and support by greatly improving the flow of technical information. This improvement will be realized by substituting an integrated digital environment, encompassing the total weapon system life cycle, for the current islands of automation linked by paper. The current prime targets for CALS are CAD/CAM data, such as engineering drawings; technical manuals, including text and illustrations; and logistic support data, such as tabular data about failure rates.

BASIC THRUSTS OF CALS

Reduce <u>cost</u>, increase <u>quality</u>, and improve <u>timeliness</u> of <u>weapon system</u> acquisition and support through <u>standards</u> for <u>information technology</u>

The current targets are

- -- design and manufacturing
- -- technical manuals
- -- logistic support

CALS Phased Development

CALS is concerned with two phases of development: the current Phase I, which provides standards for data interchange; and the future Phase II, which will provide standards for a shared Integrated Weapon System Database (IWSDB). Phase I standards are based on national and international standards; CALS has developed specific subsets or other guidance for the following:

o   the Initial Graphics Exchange Specification (IGES) for product data,

o   the Standard Generalized Markup Language (SGML) for documents,

o   CCITT Group 4 for compressed raster graphics,

o   Computer Graphics Metafile (CGM) for vector graphics, and

o   the Government Open Systems Interconnection Profile (GOSIP) for data communications.

This presentation will be primarily concerned with the Phase II standards which are now being developed.

CALS Phased Development

(Today)
Islands of Automation
Paper Flow
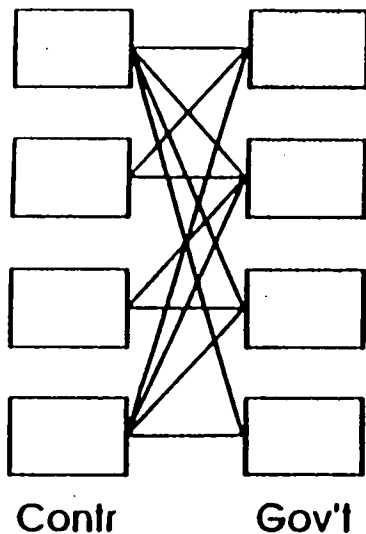
Phase I
(1988 – 92)
Interfaced Systems
Digital Flow
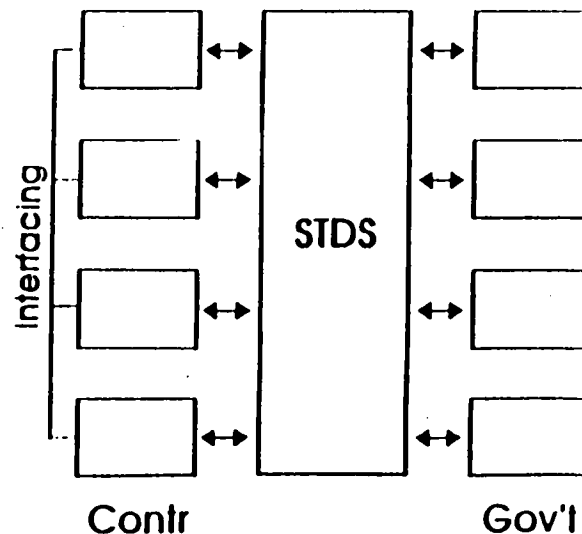
Phase II
(1991 95)
Integrated Systems
Shared Data Base

STDS

Interfacing

Integrated
Data Base

Contr   Gov't

Contr   Gov't

Contr/Gov't
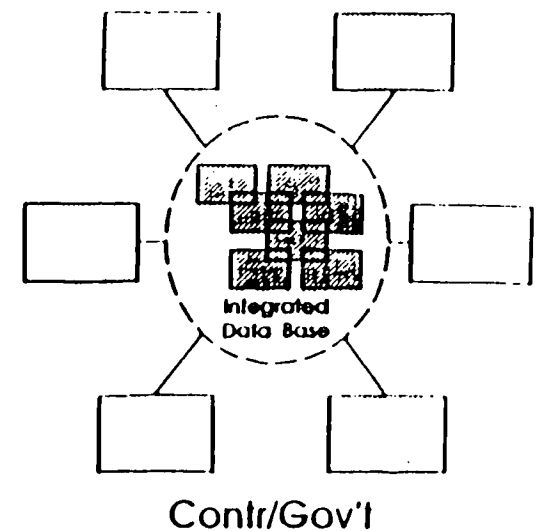
Industrial Environment - Phase II

The IWSDB will provide a means for efficient, accurate, and timely sharing of technical information among the government, the prime contractor, and subcontractors. The primary means of information delivery to the government will be a contractor-supplied information service, rather than millions of pages of paper. This will save money and time in information development, review, and maintenance. Clearly data integrity and security are critical to the operation of the IWSDB.

INDUSTRIAL ENVIRONMENT-Phase II
INTEGRATED WEAPON SYSTEM DATABASE (IWSDB)

DESIGN

TECHNICAL MANUAL
TRAINING MATERIAL
AUTHORING

IWSDB

DESIGN
ANALYSIS

INDUSTRY

MAINTENANCE
PLANNING

MFG PROCESS
PLANNING

GOVERNMENT

AUTOMATED
MANUFACTURING

SPARES
AND SERD
ORDERING

AUTOMATED
PROCUREMENT

ON-LINE
PROVISIONING

SUPPORTABILITY
ANALYSIS

STANDARD INTERFACE
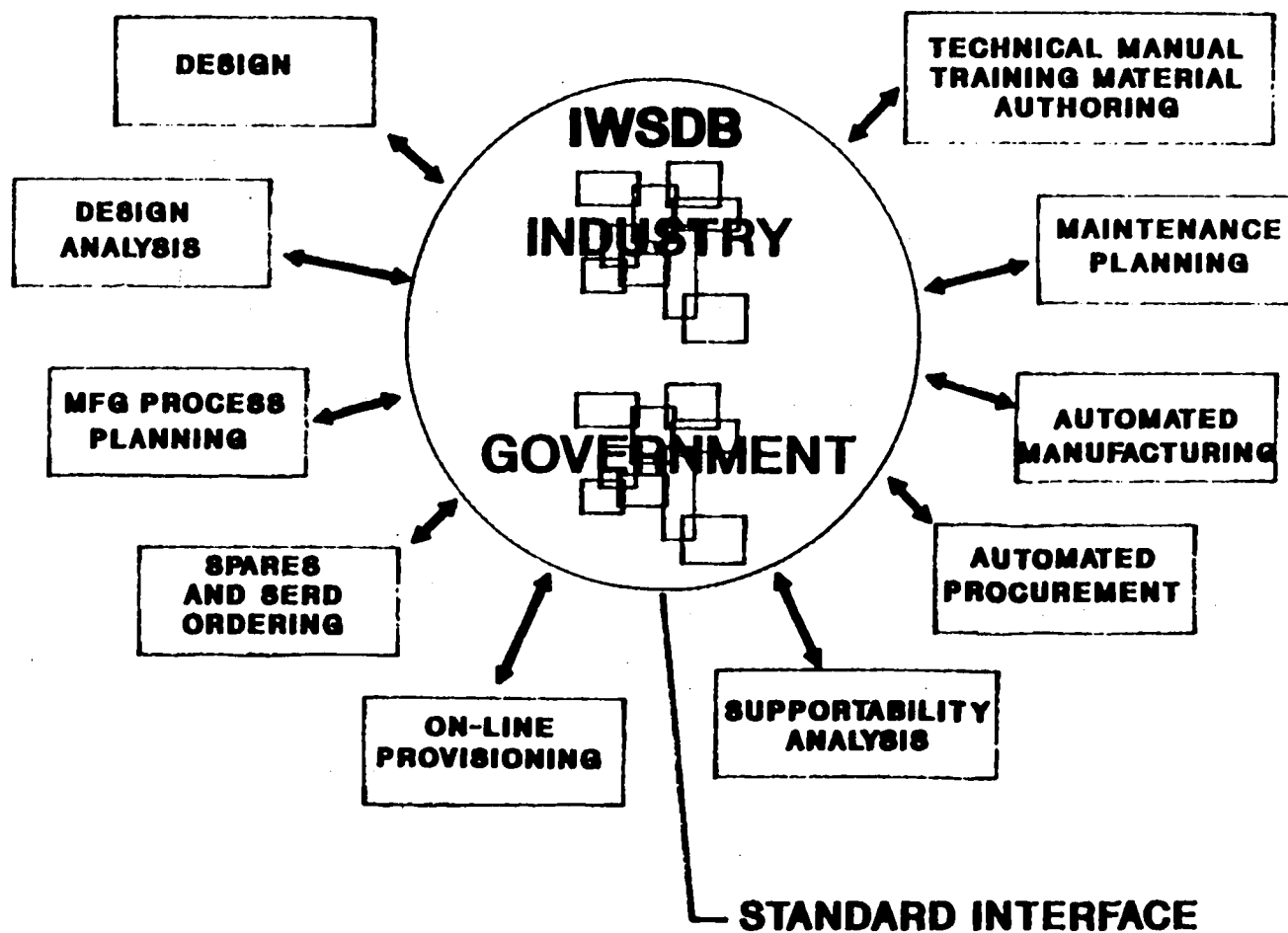
Standards

CALS is concerned with three types of standards: functional standards, such as those in military standards that describe DoD business processes; data content standards, which describe the structure and integrity rules of the data that supports those business processes; and technical standards, based on national and international standards for information technology. Technical standards provide the basis for open, non-proprietary systems only if:

o   standards are developed through consensus and supported by products from a large number of vendors, and

o   products are tested and certified by a standard procedure which provides evidence of reasonable quality.

Standards are frequently quite complex and may therefore require tailoring to a particular set of users. Very complex sets of standards, such as those of Open Systems Interconnection (OSI) may require the development of integrated profiles, or compatible tailored subsets, as in GOSIP and the Applications Portability Profile (APP).

STANDARDS

Three types:

-- Functional (shared business rules)

    example: high-cost items must be reviewed manually

-- Data content (shared vocabulary)

    example: high-cost is greater than $100,000

-- Technical (shared processing)

    example: the Structured Query Language is used for table manipulation

Requirements for effectiveness

-- Development through consensus
-- Testing and certification
-- Tailoring to users
-- Integration of compatible standards

SQL

SQL became the international and national standard for relational database management systems in October, 1986. That standard specifies a standard cursor-based interface for calling to SQL modules from a number of standard programming languages. A 1989 extension specifies a standard means of embedding SQL statements within a program for a number of standard programming languages. Application system portability is therefore possible. SQL does not yet specify an interactive interface, so ad hoc queries may or may not be portable. SQL has been widely implemented and is being significantly enhanced, as will be described later. NIST has developed an SQL test suite, which has been widely used by SQL vendors; a NIST test service will begin in April, 1990.

SQL

ISO/ANSI STANDARD: OCTOBER 1986

FEDERAL INFORMATION PROCESSING STANDARD: AUGUST 1987

PROVIDES PORTABILITY OF DATABASE DATA DEFINITION
AND DATABASE APPLICATION PROGRAMS VIA STANDARDIZED
DATA DEFINITION LANGUAGE (DDL), DATA MANIPULATION
LANGUAGE (DML), AND BINDINGS TO STANDARD PROGRAMMING
LANGUAGES COBOL, FORTRAN, AND PASCAL.

EXTENSIONS

- ● ADDENDUM1 FOR ENHANCED INTEGRITY CONSTRAINTS: 1989
- ● EMBEDDED SQL FOR ADA, COBOL, FORTRAN, PASCAL: 1989

SQL2

Two major enhancements to SQL are under development: SQL2 and
SQL3.   Both include the current SQL.   SQL2 is currently expected
to become an international and national standard in 1992.   SQL2 is
quite stable and has achieved very strong vendor support.   It
provides a standard language for dynamic creation and modification
of schema elements as well as an "information schema" which could
be used to obtain information about the structure of a database.

SQL2

ISO/ANSI STANDARD: FALL 1992

FEDERAL INFORMATION PROCESSING STANDARD: 1993

PROVIDE UPWARD COMPATIBLE ENHANCEMENTS TO SQL.

SCHEMA MANIPULATION LANGUAGE FOR DYNAMIC
CREATION AND MODIFICATION OF SCHEMA ELEMENTS.

"INFORMATION SCHEMA" FOR RUN-TIME ACCESS TO
SCHEMA INFORMATION

SQL2 (continued)

SQL2 also provides dynamic SQL, which could be used to formulate ad hoc queries. Functional enhancements include:

o   outer join to specify how null fields should be interpreted when joining tables,

o   integrity enhancement through the automatic propagation (i.e., cascade) of the results of updates and deletes,

o   standard types for date and time,

o   data type casting (i.e., type conversion), and

o   the ability to construct and use temporary tables.

SQL2 (continued)

DYNAMIC SQL FOR RUN-TIME CREATION OF SQL
STATEMENTS. VERY IMPORTANT FOR THIRD-PARTY
SOFTWARE DEVELOPERS BUILDING FOURTH GENERATION
TOOLS OVER AN SQL DATABASE.

FUNCTIONAL ENHANCEMENTS SUCH AS: OUTER JOIN,
UPDATE AND DELETE CASCADE, DOMAINS, DATE AND
TIME, CASE EXPRESSION, DATA TYPE CASTING,
STRING OPERATIONS, TEMPORARY TABLES, AND
GENERAL RELAXATION OF PREVIOUS LANGUAGE
RESTRICTIONS.

NATIONAL CHARACTER STRINGS FOR THE INTERNATIONAL
MARKET.

SQL3

SQL3 is much less well-defined than SQL2. It is likely to provide support for object-oriented databases, and could therefore support applications such as CAD/CAM. External procedure calls and user-defined data types would provide the basic capabilities for extending the relational model.

SQL3

ISO/ANSI STANDARD: 1995

FEDERAL INFORMATION PROCESSING STANDARD: 1996

WILL PROVIDE UPWARD COMPATIBLE ENHANCEMENTS TO
THE SQL STANDARDS TO SUPPORT DATA ADMINISTRATION,
KNOWLEDGE-BASE SYSTEMS, AND OBJECT-ORIENTED
DATABASE, AS WELL AS INTEGRATION WITH GRAPHICS
STANDARDS AND EXPERT SYSTEMS.

EXTERNAL PROCEDURE CALLS FOR INTEGRATION WITH
EXTERNAL SYSTEMS.

USER-DEFINED DATA TYPES, INCLUDING OPERATIONS, TO
SUPPORT OBJECT-ORIENTED DATABASES.

SQL3 (continued)

Generalization and specialization hierarchies would help support object-oriented databases. SQL3 may also provide support for data administration, including integration with the Information Resource Dictionary System (IRDS) standard to be described later. Asynchronous processing would enable a user to initiate and monitor a number of parallel operations, which would be extremely valuable in dealing with lengthy queries to many different remote databases.

SQL3 (continued)

GENERALIZATION AND SPECIALIZATION HIERARCHIES TO
SUPPORT EXPANDED SCHEMA DEFINITION.

DATA ADMINISTRATION TOOLS AND BETTER INTEGRATION
WITH IRDS STANDARDS.

ASYNCHRONOUS PROCESSING.

RECURSIVE QUERY EXPRESSIONS TO BETTER SUPPORT
BILL-OF-MATERIALS APPLICATIONS.

Information Resource Dictionary System (IRDS)

The IRDS can be considered to be a value-added database of metadata; access control and such configuration management features as version control and the use of variations provide the added value. The IRDS may be used to manage metadata describing such information resources such as programs and hardware, as well as data structures. The IRDS national standard currently specifies two interfaces: a "panel interface" that specifies functionality, and a "command language" that also specifies a concrete syntax.

INFORMATION RESOURCE DICTIONARY SYSTEM (IRDS)

ANSI STANDARD: 1988

FEDERAL INFORMATION PROCESSING STANDARD: 1989

MANAGES A POTENTIALLY LARGE VOLUME OF COMPLEX METADATA TO FACILITATE PLANNING, DESIGN, AND DOCUMENTATION FOR IRM.

ACCESS CONTROL OF METADATA.

CONFIGURATION MANAGEMENT OF METADATA.

Information Resource Dictionary System (IRDS) (continued)

The IRDS is based on entities (i.e., nouns representing objects or concepts), relationships (i.e., verbs representing associations among entities), and attributes (i.e., adjectives representing properties of entities or adverbs representing properties of relationships). A key feature of the IRDS is extensibility, i.e., the ability to define new types of metadata. For example, a new entity type called "screen" could be defined; it could "display" certain data elements and "receive" other input data elements. Communication between an IRDS and other IRDSs, database management systems, Computer-Aided Systems Engineering (CASE) tools, and other software will be enhanced by the addition of the Services Interface, for transferring small chunks of metadata, such as the attributes of a data element; and the Export/Import File Format, for transferring large chunks, such as complete schemas. In particular, the Export/Import File Format could be used to ensure the consistency of definition among a set of IRDSs.

INFORMATION RESOURCE DICTIONARY SYSTEM (IRDS) (continued)

STANDARD SET OF ENTITIES, ATTRIBUTES, AND RELATIONSHIPS (SUCH AS PROGRAM, RECORD, AND ELEMENT) FOR IRM MODELING.

EXTENSIBILITY TO SUPPLEMENT OR MODIFY THAT STANDARD SET TO ACCOMMODATE ORGANIZATIONAL TERMINOLOGY OR SPECIAL REQUIREMENTS.

DICTIONARY WILL BE ACTIVE WITH ADDITION OF IRDS SERVICES INTERFACE: 1990

DICTIONARIES WILL COMMUNICATE VIA EXPORT/IMPORT FILE FORMAT: 1990

IRDS Functionality

Examples of IRDS functionality include:

o   a planned module to enforce data element naming conventions,

o   metadata needed to drive a variety of graphically oriented CASE tools,

o   a report on the effects of change, as, for example, what records, programs, etc. could be affected by a change in the size of the ZIP code,

o   maintenance of a database architecture providing separate but interrelated definitions of the users' logical views of data, the physical representations of that data, and the consolidated enterprise view of that data, and

o   maintenance of the data content rules that provide data integrity and conformance to the business rules.

NAME ANALYSIS:
CONSISTENCY WITH POLICY

MAINTENANCE OF 3 SCHEMA
ARCHITECTURE

RELATIONSHIP ANALYSIS: GRAPHICS,
DATA DIAGRAMS, ACTIVITY DIAGRAMS,
CASE TOOL RESULTS

REPORTS TAILORED TO USERS
(E.G. SQL SCHEMA)

IRDS

INFORMATION RESOURCE
DICTIONARY SYSTEM

IMPACT OF CHANGE ANALYSIS:
DETERMINATION OF "WHAT IF""

MAINTENANCE OF DATA
INTEGRITY (VALUE
VALIDATION FOR
ENTITY-TYPES AND
ATTRIBUTE-TYPES)

INFORMATION QUALITY
ANALYSIS: CHECKING FOR
COMPLETENESS AND
CONSISTENCY WITH
POLICY

SYSTEM LIFECYCLE ANALYSIS:
REPORTS ON A PHASE; REPORTS
LINKING PHASES

Future CASE/IRDS Relationship

In the future, the IRDS will provide a common source of metadata that can be used to link various CASE tools together.

FUTURE CASE/IRDS RELATIONSHIP
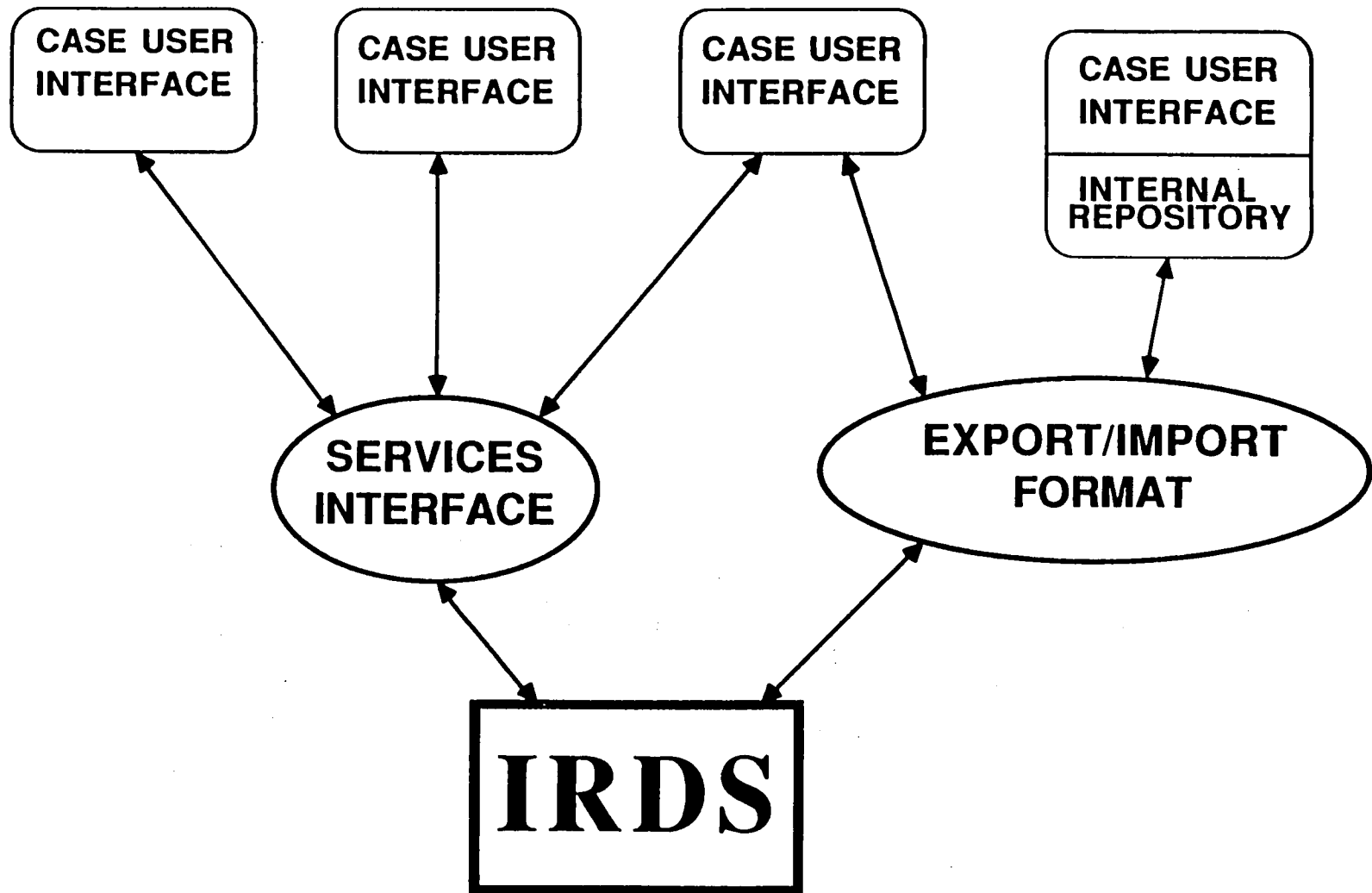
Remote Database Access (RDA)

The final database standard is Remote Database Access (RDA), which is expected to be an international and national standard in 1992. RDA will provide a standard means for sending an SQL statement to a specific remote site and receiving results and status. RDA provides only a basic capability for distributed database. It does not provide for transparent access to a data directory, nor for the decomposition of complex queries and updates, nor for the control of concurrent updates at multiple sites, nor for the recomposition of results of complex queries.

REMOTE DATABASE ACCESS (RDA)

ISO/ANSI STANDARD: 1992

FEDERAL INFORMATION PROCESSING STANDARD: 1992

WILL PROVIDE PROTOCOLS FOR REMOTE ACCESS TO
DATABASES DISTRIBUTED OVER A COMMUNICATIONS
NETWORK.

ASSOCIATION PROTOCOLS USING OPEN SYSTEMS
INTERCONNECTION (OSI) STANDARDS.

REMOTE ACCESS ONLY - DOES NOT PROVIDE DISTRIBUTED
ACCESS OR CONCURRENCY CONTROL. ONLY A FIRST STEP
TOWARD TRUE DISTRIBUTED DATABASE.

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Automatic Management of
Parallel and Distributed System Resources

- NASA Ames Research Center (Dr. Jerry Yan)

- Stanford University (Tin Fook Ngai)

Dr. Stephen F. Lundstrom

Consultant

PARSA

(415) 723-0140

Consulting Associate Professor, Electrical Engineering

Computer Systems Laboratory

Stanford University

Program Focus

(at NASA Ames Research Center)

- Parallel Processing is not confined to any one level of the software hierarchy — from applications to operating systems and machines

    - Applications must be formulated with sufficient inherent parallelism to exploit the underlying parallel architecture
      The focus in the area of parallel applications is:

        - Scalable, highly parallel symbolic applications
        - Application development environment

    - The mapping of hardware resources to the application must be able to respond to dynamic load variations and faults on the system. The focus in the area of intelligent management of multiprocessing systems is:

        - High performance and integrity
        - Highly adaptive

    - For space applications, the parallel hardware has to be subject to low weight, power and volume constraints. The focus in the performance evaluation of parallel architectures is:

        - Standardized benchmarks
        - Simulation and prediction tools for parallel systems

This is how our project fits together

- We are currently working on "parallelizing" three applications (at NASA Ames Research Center)

    - KATE — A Frame-based reasoning system monitoring the subsystem of the shuttle launch system
    - CLiPS — A C-based production system shell
    - Space Station Workloads — We are looking at the possibilities to model part of the OMA

- We are also working on resource management strategies for multiprocessors

    - "Post-Game" Analysis — Static, rule-based module assignment system
    - "Mid-Game" Analysis — Dynamic load-balancing system on hypercube type architectures

- Modeling

    - Axe — we can simulate parallel program execution of MultiComputers and Token-ring based distributed systems
    - BDL — We can model/specify parallel program behavior

- We can also "visualize" how the program executed and in turn, discover bottlenecks due to software and hardware architectural characteristics. (contact Dr. Jerry Yan at NASA Ames Research Center to request a short demonstration video tape.)

Stanford University - Computer Systems Lab.

Dynamic Concurrent Program and Its Resource Allocation

Our research (at Stanford University) has been primarily focused on dynamic concurrent programs that create
networks of communicating sequential processes during their course of execution. These networks of processes are
defined dynamically. Run-time variables include the number and type of processes to be spawned and how these
processes communicate. The number of available processors is another run-time variable. Once a network is
created, these run-time variables remain unchanged.

The resource allocation problem is how to assign the concurrent processes to available processors and how to schedule
them for fast program execution. This problem is known to be a difficult and tedious one. The objective of our
research is to investigate automatic means to this resource allocation problem.

Dynamic Concurrent Programs

create networks of communicating sequential processes
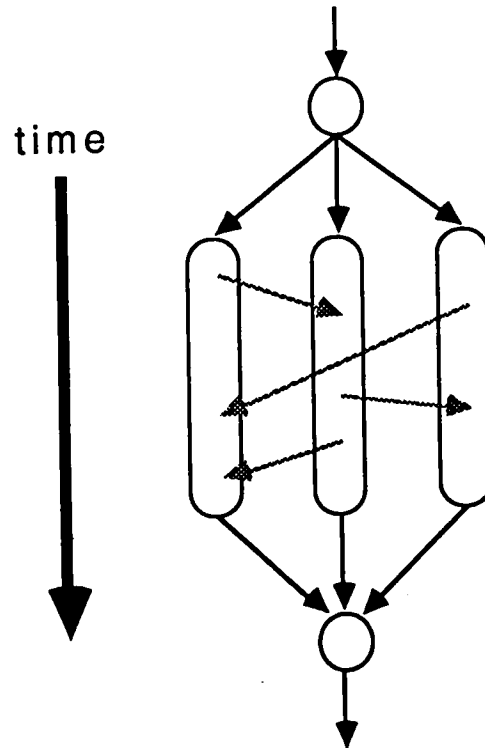
time

run-time variables:

1. # processes

2. process types

3. inter-process
   communications

4. # available processors

Resource Allocation:
- Assign processes to avail. processors
- Schedule process execution

Compiler-Directed System Approach

We believe that both program-specific information and system information should be fully utilized in order to achieve good resource allocation. Our approach to automatic resource allocation is to extract program-specific information during compile-time and to do resource allocation based on these information and other run-time scheduling parameters during run-time. During compile-time, the compiler also modifies the program by inserting in run-time calls to the run-time resource management system. During program execution, when a network of concurrent processes is about to be created, a scheduler somewhere in the system is called, and all relevant run-time scheduling parameters are gathered and passed to it. The scheduler then allocates the available processors and invoke their resident local schedulers to schedule and execute the assigned processes. We call this approach the compiler-directed system approach. (Note that the resource allocation in this approach is distributed and substantial overlapping of scheduling activities with useful computation is possible.)

234

Compiler-Directed System Approach

Compile time
- compile scheduling parameters
- insert run-time scheduling routines

Run time
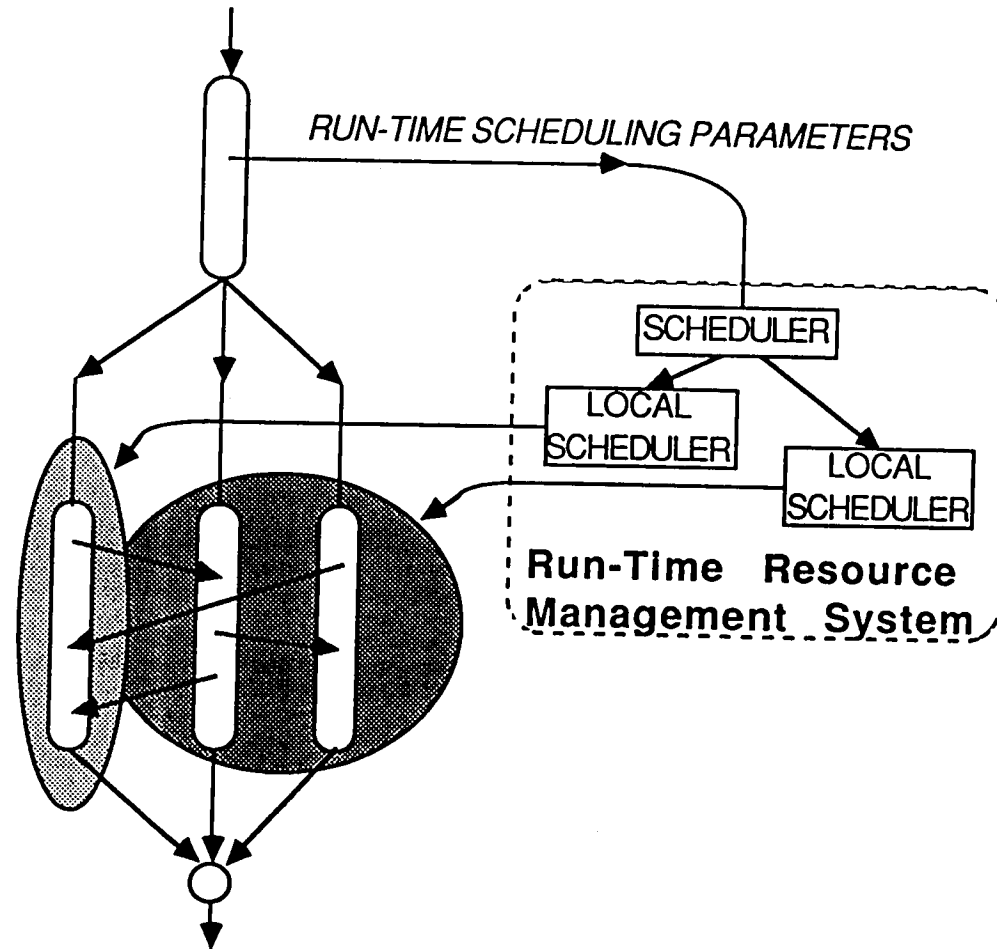
Stanford University - Computer Systems Lab.

Test Case 1 - Lattice Gaseous Cellular Automata

Experiments were performed on hypercube simulator.   System load balancing, a common system technique, which distributes the processes evenly across all available processors is used as our reference of comparison. Results obtained from commonly-adopted manual placement strategies are also compared. This test case was chosen because an ideal partitioning onto parallel resources is known. The results for the automatic, dynamic resource management technique are shown both with and without the scheduling overhead (relating to the cases where the scheduling of the dynamically spawned tasks can be done in parallel with other work, or not.)

Lattice Gaseous Cellular Automata (LGCA)

Problem Instance:

- fhp: Simulation of 256x256 point cells for 100 time steps

Program Description:

- Point-space is partitioned into 64 (8x8) macro-cells.

- Program spawns off 64 concurrent processes, one for each macro cell.

- The master process dispatches and assembles data implicitly.

(ideal allocation of resources is known for this case)

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Test Case 1 - Lattice Gaseous Cellular Automata

When the application 'lattice gaseous cellular automata' was run on full hypercubes of 4, 8 and 16 nodes, automatic scheduling performs nearly as well as the best manual placement (block placement), and obviously better than scattering manual placement (+ 8-38%) and system load balancing (+ 15-36%). Even when scheduling overhead is included, automatic scheduling is better than system load balancing (+ 8-15%).

Lattice Gaseous Cellular Automata   (LGCA)

Comparison of Automatic Scheduling on hypercubes
with Load Balancing & Manual Methods
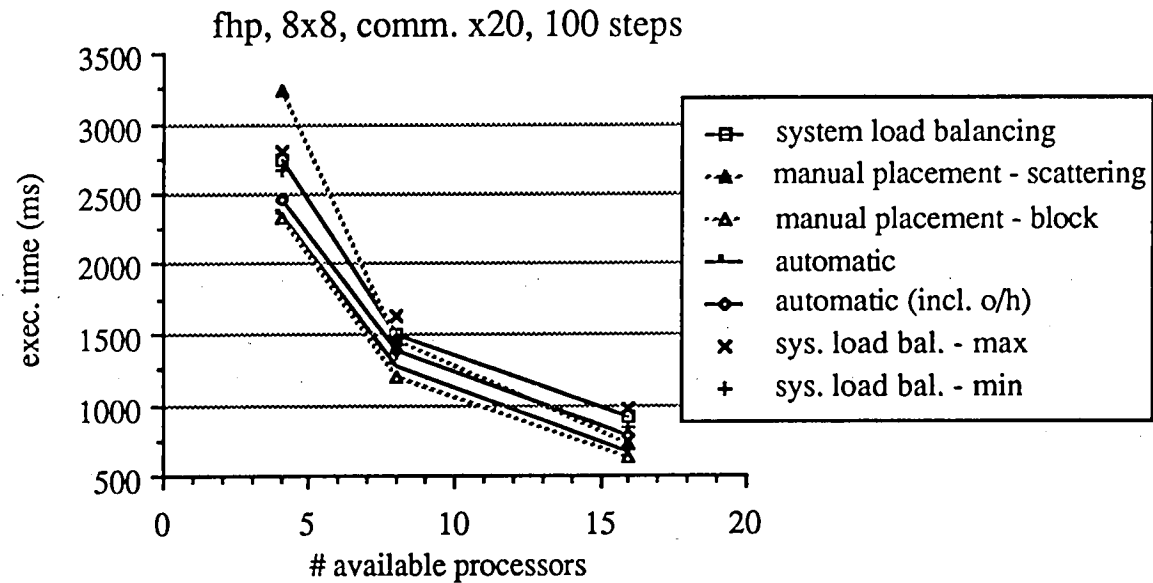
fhp, 8x8, comm. x20, 100 steps

Test Case 1 - Lattice Gaseous Cellular Automata

We believe that dynamic allocation of resources is important both in cases where the application is dynamic and in cases where the resources available in the system change dynamically. Our automatic, run-time resource allocation adapts well to changing system environments. When one node in a full hypercube is unavailable for allocation, automatic scheduling performs better than system load balancing (+ 14-28% w/o overhead, + 5-24% including overhead). Please note that automatic scheduling uses only 13 nodes when there are 15 available nodes.

Lattice Gaseous Cellular Automata   (LGCA)

Comparison of Automatic Scheduling on hypercube with one failed node with Load Balancing
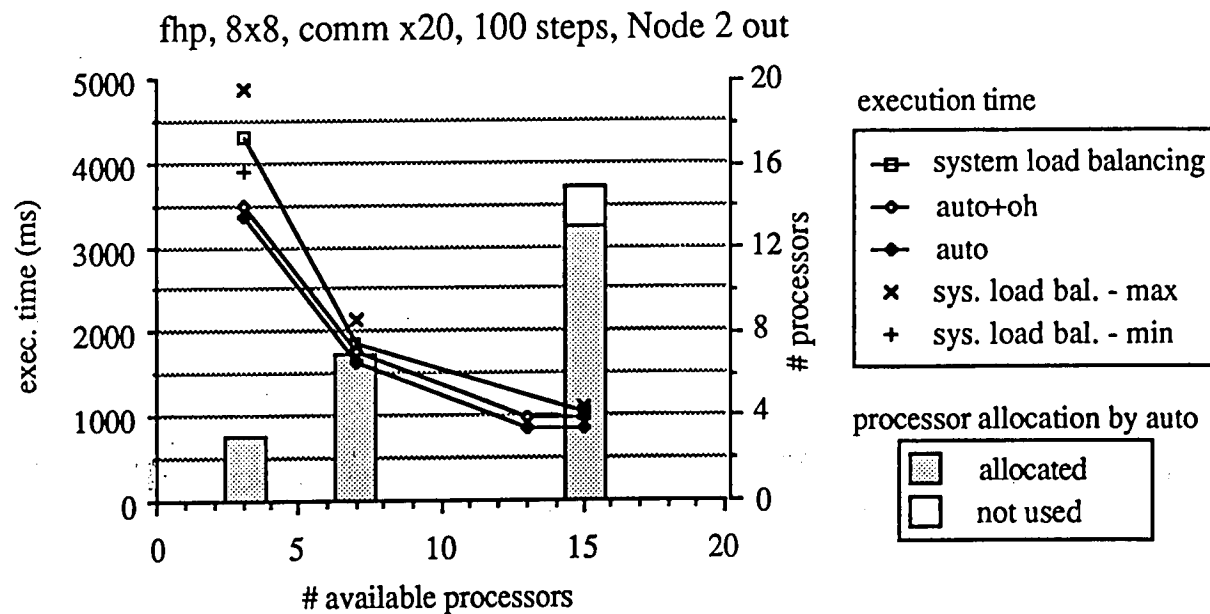
fhp, 8x8, comm x20, 100 steps, Node 2 out

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Test Case 2 - Sparse Matrix Cholesky Factorization

A portion of a sparse matrix multiplication problem is shown here as a testcase. This testcase is chosen because the number of parallel processes spawned is directly related to the input parameters and are not known until execution is in progress. Experiments were performed on hypercube simulator and results were compared with that by system load balancing. Two problem sets were tried - one related to finite element structures in aircraft design (can24) and one related to power system networks (494bps).

Sparse Matrix Cholesky Factorization

Problem Instances:

1. can24: finite element structures in aircraft design (24 columns, 96 non-zeros)
2. 494bps: power system networks   (494 columns, 1080 non-zeros)

Program Description:
- Program spawns off a concurrent process for each column.
- Each process sends and receives according to the cholesky structure

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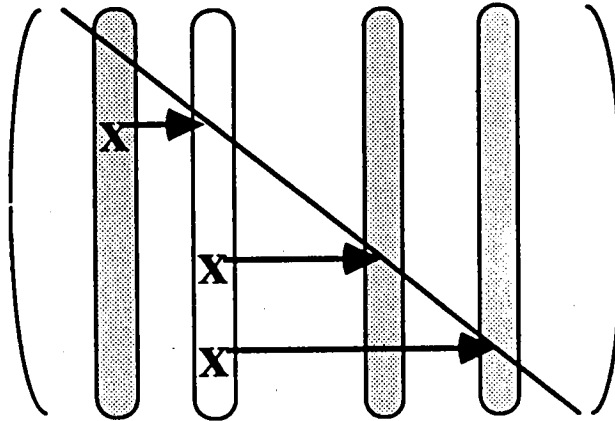
Test Case 2 - Sparse Matrix Cholesky Factorization

For the problem 'can24', automatic scheduling performs better than system load balancing when the number of available nodes is no more than 16 (+ 6-30%). System load balancing appears better (~20%) when 32 nodes are available. However, automatic scheduling allocates **at most 9 nodes** even when there are more nodes available. As a result, in the 32 processor case, the automatic scheduling method, which is using 9 nodes, is only slightly slower than system load balancing which is using 32 processors. The amount of scheduling overhead for this small problem is negligibly small.

Sparse Matrix Cholesky Factorization - can24 example

Comparison of Automatic Scheduling on hypercube with Load Balancing
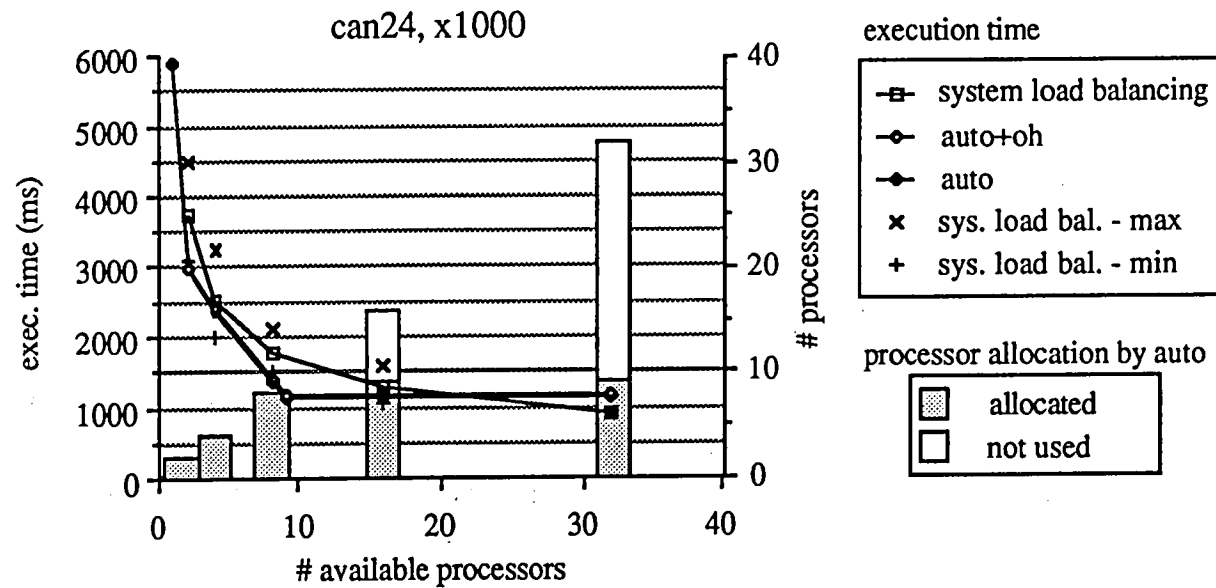
can24, x1000

Test Case 2 - Sparse Matrix Cholesky Factorization

For the larger problem '494bps', the performance of automatic scheduling is significantly better than that of system load balancing (+ 36-120% w/o overhead, + 17-95% including overhead). When a full hypercube of 32 nodes is available, automatic scheduling allocates only 25 nodes while the load balancing method is using all 32 nodes.

Sparse Matrix Cholesky Factorization - 494bps example

Comparison of Automatic Scheduling on hypercube
with Load Balancing

494bps, x1000

execution time

- ─□─ system load balancing
- ─○─ auto+oh
- ─●─ auto
- ✕ sys. load bal. - max
- + sys. load bal. - min

processor allocation by auto

- allocated
- not used

available processors
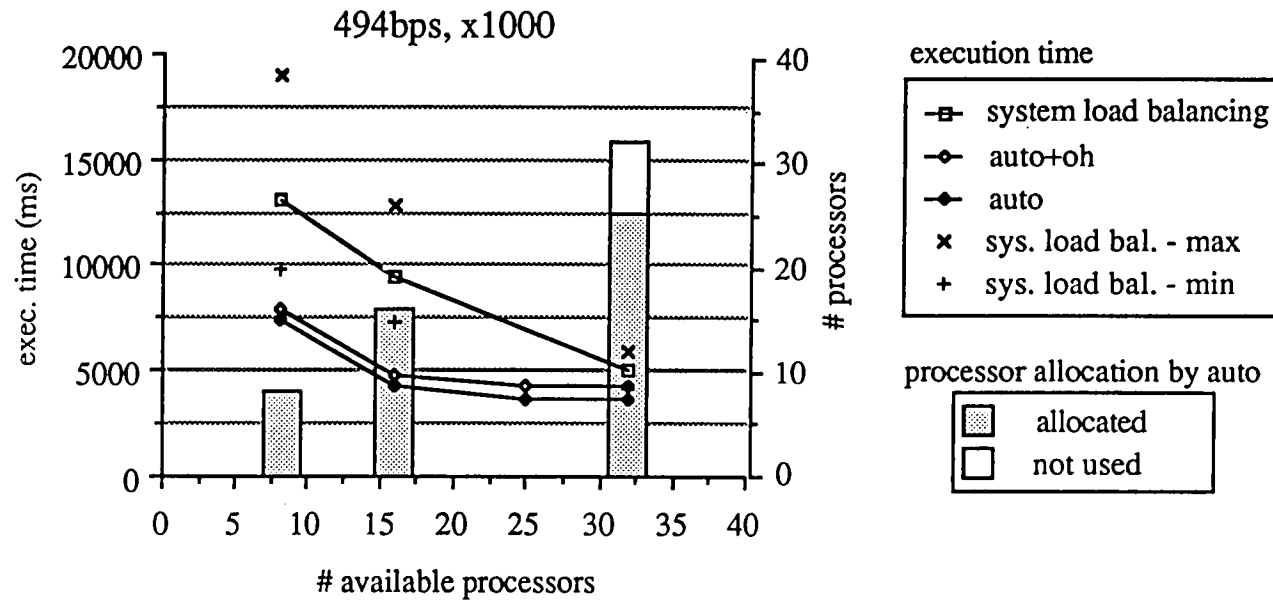
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ONBOARD SYSTEM HEALTH ASSESSMENT

TOM BARRY/JSC

HARRY CUNNINGHAM
LOCKHEED ESC
HOUSTON,TEXAS

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250

OUTLINE

BACKGROUND

SCOPE

PURPOSE

CHALLENGES/ISSUES

WHAT DO WE NEED?

DEFINITION OF PROBLEM

HOW DO WE GET THERE?

RECOMMENDATIONS

SLIDE 1

SUCCESS OF THE SPACE STATION PROGRAM WILL BE MEASURED BY
HOW WELL IT ADDRESSES THE BASIC REQUIREMENTS FOR:
1) MAINTAINING THE ORBITING SPACE STATION FREEDOM FULLY
   OPERATIONAL FOR ITS PROJECTED LIFE OF THIRTY YEARS
2) THE COST-EFFECTIVE EXECUTION OF THE OVERALL SPACE
STATION PROGRAM.
THE DEGREE OF SUCCESS WILL DEPEND ON HOW EFFICIENTLY WE
ALLOCATE, USE, AND MAINTAIN ONORBIT SYSTEMS AND RESOURCES
AND HOW SUCCESSFULLY WE AVOID WASTE OF RESOURCES, TIME,
AND DOLLARS. WE CAN'T RISK HAVING COMPLEX ONBOARD
SYSTEMS IN AN UNCERTAIN STATE OF HEALTH AT ANY TIME THEY
MAY BE NEEDED. NEITHER CAN WE AFFORD TO PROVIDE TWENTY
FOUR HOUR PER DAY GROUND BASED SURVEILLANCE OF THE HEALTH
OF ONBOARD SYSTEMS FOR THIRTY YEARS. THE ACCUMULATED
DOLLAR COST FOR MAINTENANCE OF THE NECESSARY SPECIALIZED
GROUND BASED FACILITIES AND STAFF FOR THE THIRTY YEARS
WOULD BE ENORMOUS.

THE ONLY SOLUTION IS A PROPER BALANCE OF THOROUGH AND
COMPLETE ONBOARD TESTING CAPABILITIES WITH SUPPORTING
GROUND BASED MONITORING RESOURCES AND ACTIVITIES. THE
EFFICIENCY AND EFFECTIVENESS OF THOSE CAPABILITIES AND THAT
GROUND BASED SUPPORT WILL DETERMINE THE SUCCESS OF THE
OVERALL SPACE STATION PROGRAM .

SLIDE 1

BACKGROUND

BASIC REQUIREMENTS OF THE SPACE STATION FREEDOM (SSF)

- EXPECTED 30 YEAR CONTINUOUS ONORBIT OPERATION OF SYSTEMS

- EFFICIENT ONORBIT UTILIZATION OF SYSTEMS

  - SYSTEM FUNCTIONS MUST BE AVAILABLE FOR USE
    WHEN NEEDED

  - EFFICIENT ALLOCATION AND USE OF RESOURCES IS
    MANDATORY

- EFFICIENT BALANCE BETWEEN ONBOARD AND GROUND MONITORING CAPABILITIES

SLIDE 2

ONBOARD SYSTEM HEALTH ASSESSMENT MUST PROVIDE COMPLETE
AND THOROUGH TESTING CAPABILITIES ALONG WITH EFFECTIVE
ASSOCIATED REDUNDANCY/ FAULT MANAGEMENT. THESE
CAPABILITIES MUST BE SUPPLIED FOR ALL FUNCTIONS AND
INTEGRATED COMBINATIONS, FROM THE ORU LEVEL TO THE
ULTIMATE OVERALL MULTI-SYSTEM END-TO-END SSF
CONFIGURATION. THE CAPABILITIES WILL BE SOME COMBINATION
OF AUTOMATED REDUNDANCY AND STRING RECONFIGURATION
MANAGEMENT, BUILT IN TEST/BUILT IN TEST EQUIPMENT
(BIT/BITE) AND DIAGNOSTICS, ALONG WITH A VARIETY OF
SPECIALIZED ON ORBIT END-TO- END TESTS. CREW/GROUND
MANAGEMENT OF THESE CAPABILITIES AND PERFORMANCES MUST
BE DIRECTED TO ENSURE THAT ALL ONBOARD SYSTEMS, THEIR
CAPABILITIES AND RESOURCES ARE AVAILABLE AND PROPERLY
FUNCTIONAL WHEN THEY ARE NEEDED. THAT MANAGEMENT MUST
BE WITH RECOGNITION OF THE FOLLOWING BASIC CONSTRAINTS:
1) HEALTH ASSESSMENT ACTIVITIES MUST NOT CONFLICT OR
   OTHERWISE INTERFERE WITH CRITICAL FUNCTIONS
2) THEY MUST BE DESIGNED TO AVOID UNREASONABLE DEMANDS
   FOR CREW PARTICIPATION.
3) THE SYSTEMS AND THEIR ASSESSMENT CAPABILITIES MUST BE
   DESIGNED FOR THE EASY ACCOMMODATION OF ADDITIONS AND
   MODIFICATIONS TO THE SSF SYSTEMS AND CONFIGURATION(S).

WHAT IS ONBOARD SYSTEM HEALTH ASSESSMENT?

- SCOPE

    - REDUNDANCY MANAGEMENT AND STRING RECONFIGURATION

    - BIT/BITE/DIAGNOSTICS

    - END-TO-END ONORBIT CHECKOUT

    - CREW/GROUND MANAGEMENT

- PURPOSE

    ENSURE THAT EACH ONBOARD SYSTEM IS AVAILABLE AND FUNCTIONS PROPERLY WHEN NEEDED

SLIDE 3

THE CHALLENGE : TO KEEP ALL ONBOARD SYSTEMS OPERATIONAL
FOR THE FULL TERM OF THE PROJECTED THIRTY YEAR LIFETIME
SUBJECT TO THE FOLLOWING UNIQUE AND UNUSUAL CONDITIONS
AND CONSTRAINTS:
(1) THE INITIAL FULL ASSEMBLY OF THE SPACE STATION FREEDOM
      (SSF) WILL ONLY OCCUR ONORBIT AND WILL PROVIDE THE
FIRST
      OPPORTUNITY TO CONDUCT AN END-TO-END TEST OF ITS FULLY
      INTEGRATED COMPLEX OF SYSTEMS OR TO TEST ITS SYSTEMS
IN
      THE REAL OPERATIONAL AND FLIGHT ENVIRONMENT.
   ALL SUBSEQUENT REPLACEMENTS, ADDITIONS AND
      UPGRADES MUST ALSO OCCUR ONLY ONORBIT. THERE WILL BE
NO
   "BACK TO THE GROUND " FOR CONFIRMATION OF THEIR PROPER
   INCORPORATION OR THAT THEY FUNCTION PROPERLY. THAT
   CAN ONLY BE BY WAY OF ONBOARD TESTING

(2) THE CREW MUST BE CONTINUALLY ASSURED THAT EVERYTHING
   IS FUNCTIONING PROPERLY AND THAT ALL SYSTEM RESOURCES
   ARE OR WILL BE AVAILABLE WHEN NEEDED. OTHERWISE,
   THEY WILL BE SUBJECT TO WORRY ABOUT THE STATUS OF THEIR
   EQUIPMENT WHICH WILL IMPACT THEIR EFFICIENCY.

(3) ONORBIT HEALTH ASSESSMENT MUST BE ACCOMPLISHED WITH
   MINIMAL IMPACT ON NORMAL OPERATIONS, ONLY REASONABLE
   DEMAND FOR CREW PARTICIPATION AND WITHOUT
   INTERFERENCE TO CRITICAL FUNCTIONS OR IMPORTANT ONGOING
   ACTIVITIES.

(4) A THIRTY YEAR LIFE OF GROWTH AND CHANGE MUST BE
   ANTICIPATED. THAT GROWTH WILL INCLUDE UPGRADES AND
   ADDITIONS TO INCREASE EFFICIENCY, CAPACITY AND SCOPE OF
   CAPABILITIES. PROVEN NEW TECHNOLOGY WILL BE
   INCORPORATED INTO THE SSF AS IT BECOMES AVAILABLE.

SLIDE 3

CHALLENGES AND ISSUES

ACCOMPLISHING, WITH MINIMAL IMPACT ON NORMAL OPERATIONS AN REASONABLE DEMANDS FOR CREW PARTICIPATION, THE FOLLOWING:

- MAINTAIN ONBOARD SYSTEMS OPERATIONAL FOR 30-YEAR SSF LIFETIME

- NO RETURN TO GROUND FOR MAINTENANCE OR OVERHAUL

- REPLACEMENTS, ADDITIONS, AND UPGRADES ONORBIT ONLY

- ONBOARD CAPABILITY TO ASSURE CREW THAT SYSTEMS ARE FUNCTIONING PROPERLY AND SYSTEM RESOURCES ARE AVAILABLE AS NEEDED

- ACCOMMODATE CONTINUED SYSTEM GROWTH AND FREQUENT CHANGES IN STATION CONFIGURATION AND SOFTWARE

SLIDE 4

THE PROBLEM OF ARRIVING AT THE NECESSARY LEVEL OF HEALTH
ASSESSMENT CAPABILITY IS MULTI-FACETED. THE FOLLOWING ARE
SOME OF THE PROGRAMMATIC ISSUES.

(1) CURRENT FUNDING AND SCHEDULE CONSTRAINTS PREVENT EARLY
    IMPLEMENTATION AND USE OF THE "IDEAL SSF ONBOARD
    HEALTH ASSESSMENT SYSTEM". SOME CAPABILITIES REQUIRED
    FOR THAT "IDEAL" SYSTEM ARE BEING DEFERRED TO GROUND
    MONITORING WHILE OTHERS ARE CURRENTLY CONSIDERED ONLY
    POTENTIALS FOR GROWTH.

(2) R/D OF APPLICABLE TECHNOLOGIES IS FOCUSED ON PROBLEMS
    SIGNIFICANTLY DIFFERENT FROM THOSE OF THE SSF.
    THEY GENERALLY FAIL TO RECOGNIZE PROPERTIES THAT ARE
    UNIQUE TO THE SSF PROGRAM, SUCH AS ITS THIRTY YEAR STAY
    IN ORBIT WITHOUT RETURN TO EARTH, ITS COMMITMENT TO
    TECHNOLOGICAL GROWTH AND ITS CHANGEABLE TIME
    CRITICALITY.

(3) THERE HAS BEEN AND STILL IS, THE PROBLEM OF GETTING
    EXPERTISE OF OTHER NASA RESEARCH CENTERS TO BEAR ON THE
    THE FULLY INTEGRATED MULTI-SYSTEM SSF HEALTH
    ASSESSMENT PROBLEM. TO THIS POINT THEIR TENDENCY
    HAS BEEN TO FOCUS ONLY ON WORK PACKAGE OR SYSTEM
    RESPONSIBILITIES.

SLIDE 4

DEFINITION OF PROBLEM

PROGRAMMATICS

- CURRENT FUNDING/SCHEDULE CONSTRAINTS PREVENT DESIGN/DEVELOPMENT OF AN IDEAL SYSTEM.

  - CURRENT SSF ONBOARD SYSTEM HEALTH ASSESSMENT IS LIMITED, (LESS THAN IDEAL).

  - SOME CAPABILITIES HAVE BEEN DEFERRED TO GROUND MONITORING.

- TECHNOLOGY DEVELOPMENT - IS ISOLATED FROM REAL WORLD SYSTEM LIMITATIONS AND IS NOT FOCUSED ON THIS PROBLEM.

- UNIQUE PROBLEM - ie 30 YEARS OF OPERATION WITH REPAIR SHOP LOCATED THOUSANDS OF MILES AWAY.

- DIFFICULTY IN GETTING EXPERTISE OF OTHER NASA RESEARCH CENTERS TO BEAR ON THE PROBLEM.

259

SLIDE 5

UNDER THE CURRENT SSF DEVELOPMENT PLAN THE ONBOARD
HEALTH ASSESSMENT REQUIREMENTS WILL DEPEND ON THE STATE
OF SSF DEVELOPMENT. THE REQUIRED ASSESSMENT CAPABILITIES
WILL GROW FROM BARE MINIMUM FOR PMC (PERMANENTLY
MANNED CONFIGURATION) TO THOSE FOR A SUBSTANTIAL SYSTEM
WITH A FAIR AMOUNT OF AUTOMATION AT AC (ASSEMBLY
COMPLETE). FROM AC FORWARD (MATURITY AND GROWTH), THE
REQUIREMENT WILL BE TO GROW ONBOARD HEALTH ASSESSMENT
CAPABILITIES IN SCOPE EFFICIENCY AND AUTOMATION, ADOPTING
NEW APPLICABLE TECHNOLOGY AS IT BECOMES AVAILABLE. THE
DIFFERENCES IN THE REQUIREMENTS FOR THE THREE STATES OF
DEVELOPMENT ARE SIGNIFICANT AND DESERVE DEEPER
CONSIDERATION. LET'S LOOK AT EACH IN TURN.

NOTE: THE DIFFERENCES BETWEEN PMC AND AC ARE MADE OBVIOUS
    IN THE REQUIREMENTS DOCUMENT JSC 31000. ITS
    STATEMENTS OF REQUIREMENTS ARE ACCOMPANIED BY
    DESIGNATIONS AS TO WHETHER THEY ARE TO BE ENFORCED AT
    PMC OR AC.

SLIDE 5

SSF HEALTH ASSESSMENT REQUIREMENTS

- REQUIREMENTS DIFFER DEPENDING ON STATE OF SSF DEVELOPMENT

    - SOME REQUIREMENTS HAVE BEEN DEFERRED FROM PMC (PERMANENTLY MANNED CONFIGURATION) TO AC (ASSEMBLY COMPLETE)

    - MANUAL/ GROUND FOR PMC

    - AUTOMATIC/ONBOARD WITH GROUND SUPPORT FOR AC

- STATES OF SSF DEVELOPMENT

    - PMC

    -AC

    - MATURITY/GROWTH

SLIDE 6

UNDER THE CURRENT SSF DEVELOPMENT PLAN, AT PMC ONLY A
BARE MINIMUM OF ONBOARD HEALTH ASSESSMENT ASSOCIATED
CAPABILITIES WILL BE AVAILABLE. THE ONLY ASSOCIATED
AUTOMATION IS THE FAULT DETECTION,ISOLATION AND RECOVERY
(FDIR) PROVIDED FOR CRITICALITY 1 (CREW SAFETY CRITICAL)
FUNCTIONS. FOR THOSE, THE FDIR IS TO THE ORU LEVEL AND
REDUNDANCY SWITCHOVERS ARE AUTOMATIC. ASIDE FROM THAT,
THE ONLY ONBOARD ACTIVITIES ASSOCIATED WITH HEALTH
ASSESSMENT AND MAINTENANCE IS THE ACQUISITION OF
DIAGNOSTIC DATA, THEIR TRANSFER TO THE GROUND FOR ANALYSIS
AND ASSESSMENT AND CREW INITIATED CORRECTIVE ACTIONS
DIRECTED FROM THE GROUND. THE PRIMARY CONTROL FOR THOSE
ACTIVITIES IS FROM THE GROUND BASED OPERATIONS
MANAGEMENT GROUND APPLICATION (OMGA) WITH CREW SUPPORT.
THE DATA ACQUIRED ONBOARD AND ISSUED TO THE GROUND ARE
DIAGNOSTIC DATA DERIVED FROM INSTALLED BIT/BITE ALONG
WITH DMS, REDUNDANCY AND CONFIGURATION STATUS DATA.
THE OUTSTANDING FEATURE OF THIS METHODOLOGY IS THE GROUND
BASED TIER 1 CONTROL.

PMC

- MINIMAL REQUIREMENTS

    - FAULT DETECTION/ISOLATION TO ORU FOR CRITICALITY 1 FUNCTIONS ONLY

    - AUTOMATED RM FOR CRITICALITY 1 (SAFETY CRITICALS) ONLY

- PRIMARY CONTROL FROM GROUND (OMGA) WITH CREW SUPPORT

    - ASSOCIATED CREW ACTIVITY IN RESPONSE TO GROUND DIRECTION

- METHODOLOGY

    - DIAGNOSTICS COLLECTED ONORBIT VIA BIT/BITE AND TRANSMITTED TO GROUND FOR ANALYSIS AND FAULT DIAGNOSIS (JSC 31000 Par. 3.1.19.3)

    - CREW/GROUND DIRECTED RECONFIGURATIONS TO REDUNDANT FUNCTIONS (NOT AUTOMATIC) (JSC 31000 Par. 3.1.8.7.1)

    - CONFIGURATION AND REDUNDANCY STATUS DATA ARE SENT TO THE GROUND (SIGNIFICANT OMA FUNCTIONALITY DEFERRED TO OMGA FOR PMC)

SLIDE 7

AT AC THE PRIMARY (TIER 1) CONTROL SHIFTS FROM THE OMGA TO
THE ONORBIT OMA (OPERATIONS MANAGEMENT APPLICATION),
WITH OMGA AND CREW IN SUPPORTING ROLES. SYSTEM AND INTRA-
SYSTEM CONTROL WILL BE BY LOWER TIER (SYSTEM) MANAGEMENT.
ALSO AT AC, THERE WILL BE THE CAPABILITY FOR FAULT
DETECTION/ISOLATION TO THE ORU LEVEL, WITH REDUNDANCY AND
AUTOMATED REDUNDANCY MANAGEMENT EXPANDED TO COVER ALL
SAFETY AND MISSION CRITICAL FUNCTIONS. THE INITIAL AC
HEALTH MONITORING AND MAINTENANCE CAPABILITIES WILL BE
THOSE FOR SATISFACTION OF BASELINE OPERATIONAL SSF
REQUIREMENTS. THEY WILL INCLUDE FULLY AUTOMATED FDIR FOR
HIGH LEVELS OF CRITICALITY (CREW SAFETY AND MISSION) AND
BIT/BITE CAPABLE OF FAULT DETECTION/ISOLATION TO THE
ORU/ORU INTERFACE LEVEL. DMS WILL BE PROVIDED WITH
AUTOMATED FDIR AND RM AND CONFIGURATION STATUS
MONITORING AND LOGGING WILL BE AUTOMATED. PRIOR TO THIS,
DMS ONLY SUPPLIED DIAGNOSTICS, STATUS AND CONFIGURATION
DATA. THESE WILL BE THE PROPERTIES AND FEATURES OF THE
BASELINE OPERATIONAL SSF HEALTH ASSESSMENT SYSTEM.

SLIDE 7

AC

- SATISFIES BASELINE OPERATIONAL REQUIREMENTS

    - FAULT DETECTION/ISOLATION TO THE ORU/ORU'S INTERFACING
      SYSTEM / SOFTWARE (JSC 31000 PAR. 3.1.8.3.1)

    - EXPANDED REDUNDANCY AND AUTOMATED RM FOR SAFETY AND MISSION
    CRITICAL FUNCTIONS - EXPANDED ROLE OF BIT/BITE (INTRA/INTER-SYSTEM
    TESTING)

- PRIMARY GLOBAL CONTROL IS OMS (OMA) WITH OMGA/CREW SUPPORT

    - LOWER TIER CONTROL FOR INTER/INTRA SYSTEM

- METHODOLOGY

    - AUTOMATED FDIR FOR HIGH LEVELS OF CRITICALITY

    - BIT/BITE FOR FAULT DETECTION/ISOLATION TO ORU/ORU INTERFACE

    - CAPABILITY FOR ON-DEMAND AUTOMATED STATUS CHECKS

    - DMS PROVIDED WITH AUTOMATED FDIR (JSC 31000, PAR. 3.3.2.6.2)

    - AUTOMATED CONFIGURATION/ RM STATUS MONITORING/LOGGING

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SUMMARY OF THE DIFFERENCES

Reference Par. (page(s))	PMC Requirement	AC Requirement
3.1.5.4 (3-10/11)	Onboard/ground operations sequencing override capability	Design for autonomous operations for a TBD period with sequencing override capability
3.1.8.3.5 (3-17)	automatic FDIR for criticality 1 only RM/RM status to crew/ground	automatic RM with status to ground, crew and other automated applications
3.1.8.7.2 (3-25)	automatic RM reconfiguration for safety criticals only - others are manual (crew/ground)	Onorbit automation for elimination of need for realtime continuous monitoring by SSMB ground personnel
3.1.24.2.2 (3-86/87)	overall control by OMGA with crew support	control by OMA with crew/ground support
3.1.24.3.4.8 (3-9)	Primary recovery mode for station wide functional failures is manual/ground process with limited automation	Primary recovery mode is automatic with manual support
3.3.2.2.1.2 (3-134)	Single DMS network (core)	Double DMS network (core/payload)
3.3.2.3.1.2.8 (3-167 thru 3-169)	Fault Detection and reconfiguration by OMA	Fault management and reconfiguration by OMA
3.3.2.3 (3-154 thru 3-190)	Primary control by OMGA	Primary control by OMA

* NOTE - List of some of the major differences.

SLIDE 8

SUBSEQUENT TO AC, THE REQUIREMENT WILL BE FOR A CONTINUAL
EFFORT TO IMPROVE THE ONBOARD HEALTH ASSESSMENT
CAPABILITIES. THAT EFFORT SHOULD BE DIRECTED TO ACHIEVE
TOTAL RELIABILITY, COMPLETE END-TO-END SSF COVERAGE AND
TOTAL AUTONOMY OF HEALTH ASSESSMENT. THE ULTIMATE GOAL
SHOULD BE TO PROVIDE AN ONBOARD HEALTH ASSESSMENT AND
MAINTENANCE SYSTEM HAVING ALL THESE PROPERTIES THAT WILL
FUNCTION WITH MINIMUM DEMAND FOR CREW ATTENTION. THIS
GOAL SHOULD BE KEPT IN MIND THROUGHOUT THE LONG
OPERATIONAL LIFE OF THE SSF. AS APPLICABLE NEW
METHODOLOGIES ARE DEVELOPED AND TECHNOLOGIES ARISE, THEY
SHOULD BE INCORPORATED INTO THE ONBOARD SYSTEMS TO
ENHANCE THE HEALTH ASSESSMENT AND MAINTENANCE
CAPABILITIES. THIS SHOULD BE AN ONGOING ACTIVITY, SINCE THAT
CAPABILITIES EVOLUTION PROCESS WILL PROVIDE DEFINITION FOR
USE IN OTHER PROGRAMS INVOLVING COMPLEX SYSTEMS WITH
LONG OPERATIONAL LIFES.

SLIDE 8

<u>MATURITY/GROWTH</u>

- REQUIREMENT IS FOR CONTINUAL ENHANCEMENTS AIMED AT:

    - INCREASED RELIABILITY

    - INCREASED COVERAGE

    - LESSENING DEMANDS ON CREW

    - INCREASE OF SSF AUTONOMY

    - END-TO END AUTOMATION OF HEALTH SURVEILLANCE AND MAINTENANCE
      (IDEALIZED GOAL)

- METHODOLOGY(IES)???

269

REASONABLE SATISFACTION OF THE SSF HEALTH ASSESSMENT
REQUIREMENTS AT PMC, AC, AND BEYOND CAN BE ENSURED THROUGH
EARLY RECOGNITION OF BASIC NEEDS IN SYSTEM DESIGN.
THAT DESIGN MUST BE DIRECTED TOWARD EFFECTIVE USE OF THE
CREW. IT MUST PROVIDE AN EFFICIENT AND RELIABLE ONBOARD
SYSTEM HEALTH ASSESSMENT/ MAINTENANCE CAPABILITY TO
ENSURE CONTINUAL CREW CONFIDENCE IN THEIR EQUIPMENT.
EXERCISE OF THAT CAPABILITY MUST BE WITHOUT ADVERSE
IMPACT ON NORMAL OPERATIONS OR THE DEMAND FOR THE
UNREASONABLE USE OF ONORBIT RESOURCES. DEVELOPMENT OF
PROPER DESIGN/ METHODOLOGY REQUIRES COMPLETE AND CLEAR
DEFINITION OF THE OVERALL HEALTH ASSESSMENT PROBLEM AND
ITS REQUIREMENTS AT PMC, AC AND BEYOND. A PLENTIFUL SUPPLY
OF HOOKS AND SCARS WILL BE REQUIRED FOR ITS PROGRESSIVE
IMPLEMENTATION. THIS IS A TOUGH DESIGN PROBLEM THAT
DEMANDS A WIDESPREAD COOPERATIVE ATTACK FOR PROPER
SOLUTION. WE NEED BETTER COOPERATION BETWEEN THE VARIOUS
NASA CENTERS AND WE NEED TO INVOLVE ACADEMIA AND
INDUSTRY RESEARCH. THE POTENTIAL FOR THE DEVELOPMENT OF
TRANSFERRABLE NEW TECHNOLOGY ALONG WITH THE CHALLENGE
PRESENTED BY THE PROBLEM SHOULD BE ATTRACTIVE INDUCEMENTS
FOR THE PARTICIPATION OF THOSE NON-NASA GROUPS.

SLIDE 9

HOW DO WE GET THERE ?

- EARLY RECOGNITION OF THE BASIC NEEDS

  - MOST EFFECTIVE USE OF CREW

  - MOST EFFECTIVE USE OF ONORBIT TIME/RESOURCES

  - MORE COMPLETE AND CLEAR DEFINITION OF THE PROBLEM

  - PLENTIFUL SUPPLY OF HOOKS AND SCARS

- WIDESPREAD ATTACK OF THE PROBLEM

  - COOPERATIVE ATTACK- NASA CENTER-TO-CENTER, ACADEMIA AND INDUSTRY R/D EFFORTS

  - SIGNIFICANT VIA POTENTIAL FOR TECHNOLOGY TRANSFER TO OTHER PROGRAMS

  - TECHNOLOGICAL ADVANCES AND NEW TECHNOLOGY

SLIDE 10

THE FOLLOWING ARE RECOMMENDED FOR THE ATTACK OF THE SSF
HEALTH ASSESSMENT AND MAINTENANCE PROBLEM

(1) ADOPT AND ENFORCE THE POLICY OF "DESIGN TO TEST". THIS
   APPROACH HAS PROVEN MOST EFFECTIVE FOR THE DEVELOPMENT
   OF TESTING AND HEALTH ASSESSMENT CAPABILITIES FOR LARGE
   AND COMPLEX SYSTEMS.

(2) MAKE CERTAIN THAT THE BASIC DESIGN OF THE SSF SYSTEMS
   INCORPORATES A PROPER AND PLENTIFUL SUPPLY OF SOFTWARE
   "HOOKS" AND HARDWARE "SCARS" TO ACCOMMODATE FUTURE
   GROWTH AND EXPANSION OF HEALTH ASSESSMENT TECHNOLOGY
   AND CAPABILITIES.

(3) STIMULATE INTEREST IN THE PROBLEM THROUGHOUT ALL NASA
   CENTERS AND NON-NASA RESEARCH ORGANIZATIONS.

(4) APPLY APPROPRIATE NEW TECHNOLOGIES TO SOLVE THE
   PROBLEM AND MAINTAIN FLEXIBILITY IN THEIR SELECTION.
   ENTERTAIN OUTGROWTHS OF PROVEN DEVELOPMENTS.
   AND THE PROSPECT OF COMBINING THE BEST FEATURES OF
   VARIOUS TECHNOLOGIES. AVOID A METHODOLOGY THAT LEADS
   TO "LOCK IN" TO A GIVEN TECHNOLOGY AND ADOPT ONE THAT IS
   ADAPTABLE TO GROWTH AND CHANGE.

RECOMMENDATIONS

- PROMOTE AND ENFORCE DESIGN/DEVELOPMENT REQUIREMENT FOR :

  - DESIGN TO TEST

  - INCORPORATION OF HOOKS/SCARS TO ACCOMMODATE EXPANDED
    CAPABILITIES/TECHNOLOGICAL GROWTH

- EXPAND ARENA OF PROBLEM RECOGNITION

  - ALL NASA CENTERS

  - ACADEMIC RESEARCHERS AND RESEARCH ORGANIZATIONS

  - INDUSTRIAL RESEARCH CENTERS/ORGANIZATIONS

- APPLY APPROPRIATE NEW TECHNOLOGIES TO OUR PROBLEM

  - OUTGROWTHS OF PROVEN DEVELOPMENTS

  - TECHNOLOGY COMBINATIONS (ASSEMBLIES OF BEST FEATURES)

273

SLIDE 11

FOR THE OPERATIONAL SSF WE NEED THE CONTINUAL ONBOARD
CAPACITY TO ENSURE CREW AND MISSION SAFETY, OPERATIONAL
READINESS AND SUFFICIENT PERFORMANCE RESERVES TO COPE WITH
ANY UNFORESEEN EMERGENCY THROUGHOUT THE ONORBIT LIFE OF
THE SSF. WE NEED A COMPLETE AND RELIABLE ABILITY TO
EFFECTIVELY COPE WITH ANY FAULT OR FAILURE. WE NEED THE
ONORBIT ABILITY TO VERIFY THAT ALL REPAIRS, REPLACEMENTS,
UPGRADES AND ADDITIONS INTRODUCED TO THE OPERATIONAL SSF
ARE PROPER AND CORRECT. WE NEED THE ONORBIT ABILITY TO
CONDUCT THE TESTING NECESSARY TO ESTABLISH FULL CONFIDENCE
IN THE EQUIPMENT AT ANY TIME. WE NEED THE ONORBIT ABILITY
TO BE ASSURED THAT THAT ONBOARD TESTABILITY IS RELIABLE
AND EFFICIENT.

WHAT DO WE NEED?

- ABILITY TO ISOLATE FAULTS AND FAILURES TO AN ORU - 100%.

- ABILITY TO ISOLATE FAULTS & FAILURES TO THE CARD OR SRU (FOR CERTAIN CARDS ie EDP)- 90%.

- ABILITY TO RECOVER FROM ALL FAULTS (TRANSIENTS OR PERMANENT).

- ABILITY TO WORK AROUND FAILURES.

- ABILITY TO ENSURE THAT S/W UPGRADES & CHANGES ARE INSTALLED PROPERLY AND PERFORM AS EXPECTED.

- ABILITY TO CONFIGURE SYSTEM FOR TESTING DURING GROUND OPERATION OR "ON DEMAND".

- ABILITY TO VERIFY SYSTEM/STATION CONFIGURATION/RECONFIGURATION & MODING AT ANY TIME.

- ABILITY TO DO TEST RESULTS PREPROCESSING ONBOARD TO REDUCE TELEMETRY/GROUND SUPPORT BURDEN.

- NEW DESIGNS UTILIZE/TESTABILITY TOOLS DURING DESIGN/DEVELOPMENT PHASE TO ENSURE ONORBIT TEST EFFICIENCY.

275

SLIDE 12

CONSIDERING THE SCOPE OF THE PROBLEM, THERE APPEARS TO BE NO EXISTING TECHNOLOGY THAT, TAKEN ALONE, CAN SATISFY ALL OUR REQUIREMENTS. THE PRIME CANDIDATES, AUTOMATED KNOWLEDGE BASED AND EXPERT DIAGNOSTIC SYSTEMS, APPEAR INADEQUATE AT THEIR CURRENT LEVEL OF DEVELOPMENT. THIS IS ALSO TRUE FOR TH CONVENTIONAL BIT/BITE. ONE PROBLEM WITH THESE IS THAT THE FOCUS OF THEIR DEVELOPMENTS TO THIS TIME HAS HAVE BEEN GENERALLY LIMITED TO LOW LEVELS OF ARCHITECTURE (REPLACEABLE UNITS AND SUBSYSTEMS). A SECOND PROBLEM IS THAT MOST HAVE BEEN DESIGNED TO PROVIDE DIAGNOSTICS FOR AFTER- THE- FACT, IN-SHOP USE. OUR REQUIREMENT IS FOR THE ADDRESS OF FULL AND INTERSYSTEM FAULT/FAILURE MANAGEMENT ONORBIT. THE DEMAND IS FOR NEW TECHNOLOGY THAT, PERHAPS BUILDS ON THESE EXISTING ONES, BUT THAT HAS ADDED SCOPE AND CAPABILITIES. THE INCORPORATION OF ONBOARD SOFTWARE SIMULATIONS AND MODELS INTO KNOWLEDGE BASED EXPERT SYSTEMS APPEARS TO BE ONE ATTRACTIVE POSSIBILITY. DESIGN TO TEST OF SYSTEMS (SYSTEM LEVEL BIT/BITE AND DIAGNOSTICS) IS A SECOND. FINALLY, WHAT ABOUT AN ONBOARD COMPUTER DEDICATED TO SYSTEM/INTER-SYSTEM TESTING ?

FOOD FOR THOUGHT

- <u>POTENTIAL TECHNOLOGY</u>

  - ONBOARD USE OF SOFTWARE SIMULATIONS AND MODELS

  - EXPERT SYSTEMS

  - KNOWLEDGE BASED AUTOMATED SYSTEMS

    - RULE BASED

    - MODEL BASED

    - OTHERS

  - SYSTEM LEVEL BIT/BITE/DIAGNOSTIC DESIGN

  - NEED FOR DEDICATED ONBOARD TEST COMPUTER?

SLIDE 13

LET ME EXPAND A BIT ON THE NOTION OF INCORPORATING MODELS
AND SIMULATIONS INTO KNOWLEDGE BASED SYSTEMS. WHY IS
THAT POSSIBILITY SO ATTRACTIVE ? FIRST THEY WILL BE READILY
AVAILABLE (DEVELOPED, AND GROWN TO MATURITY IN THE
GROUND BASED IT&V PROGRAM). SECONDLY THEIR ONBOARD USE IS
DEMANDED TO BYPASS CRITICAL FUNCTIONS DURING INTEGRATED
TESTING. FINALLY, A GREAT DEAL OF DESIGN KNOWLEDGE IS
NATURALLY EMBEDDED IN THOSE MODELS AND THEY CAN BE
EFFECTIVELY EMPLOYED TO GROW KNOWLEDGE THROUGH THEIR USE
TO PROVIDE STANDARDS FOR PERFORMANCE COMPARISONS.
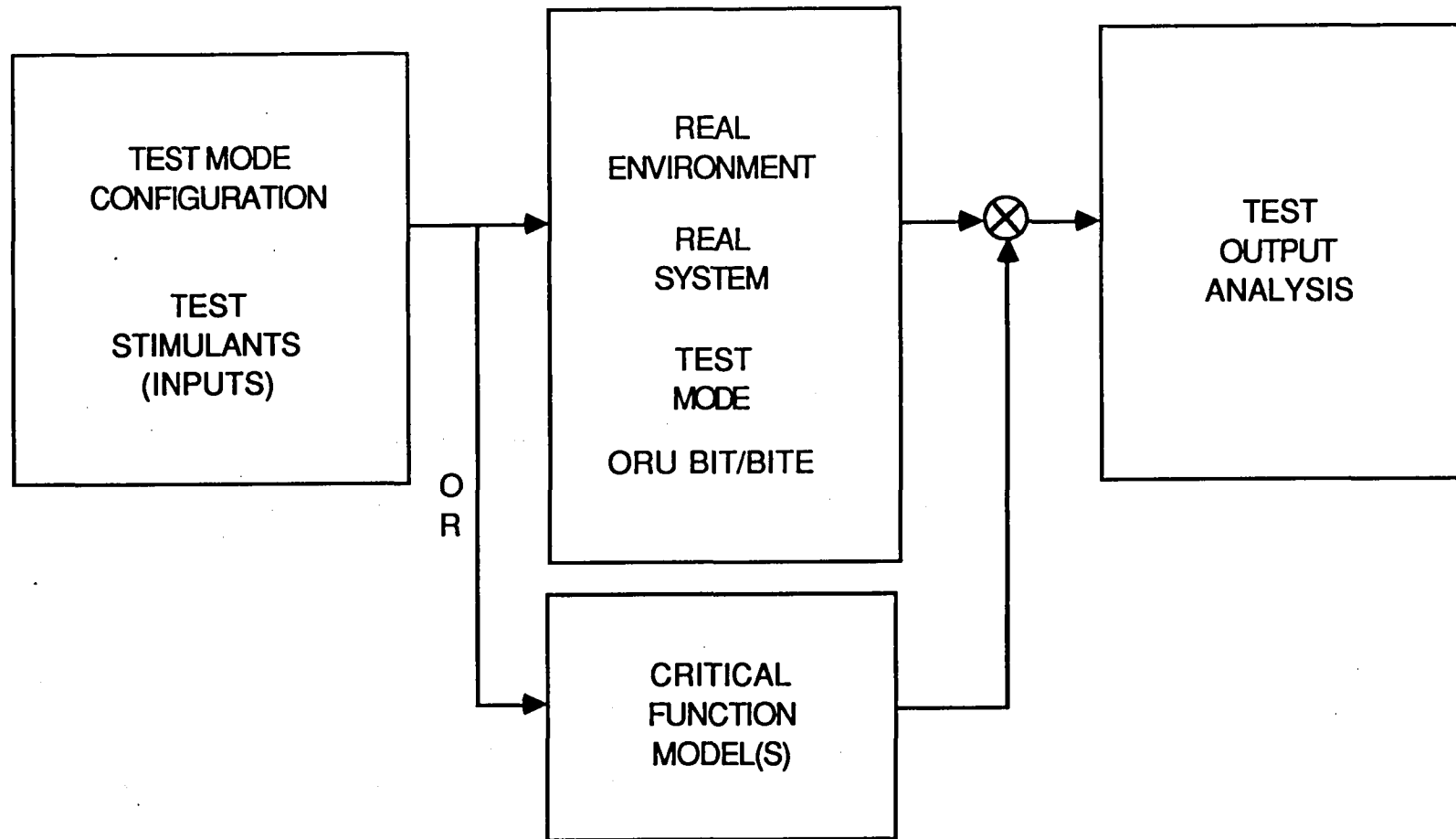
NON INTERFERENCE TESTING

SLIDE 14

CRITERIA FOR THE MEASUREMENT OF PERFORMANCE AND BEHAVIOR
FOR FUNCTIONAL SYSTEMS AND COMPLEXES OF SYSTEMS WILL BE
DIFFICULT, IF AT ALL POSSIBLE, TO DESCRIBE COMPLETELY AND
ACCURATELY IN THE SYMBOLIC FORM REQUIRED BY CONVENTIONAL
KNOWLEDGE BASES. THIS IS TO SUGGEST THAT SOFTWARE
SIMULATIONS AND MODELS CAN BE EFFECTIVELY USED FOR THAT
PURPOSE. THEY CAN BE EMPLOYED IN PARALLEL WITH REAL
SYSTEM OPERATIONS TO PROVIDE STANDARDS FOR PERFORMANCE
COMPARISONS. THOSE STANDARDS MAY BE OF IDEAL PERFORMANCE
FOR THE MONITORING OF SYSTEM PERFORMANCE OR MAY BE
SPECIALIZED FOR TESTING CONDUCTED TO ACQUIRE DIAGNOSTICS
SHOULD THAT PERFORMANCE PROVE TO BE OUT OF TOLERANCE. SUCH
USES WILL YIELD VALUABLE KNOWLEDGE REGARDING SYSTEM
PERFORMANCE CHARACTERISTICS AND TRENDS. THEY MAY ALSO BE
EMPLOYED FOR "WHAT IF" STUDIES TO EXPAND KNOWLEDGE
REGARDING SYSTEM PERFORMANCE AND BEHAVIOR. FOR EXAMPLE,
THEY MAY BE MANIPULATED TO SIMULATE SOME FAULT, FAILURE
OR OFF NOMINAL CONDITION TO ESTABLISH SYSTEM HEALTH
EVALUATION CRITERIA.
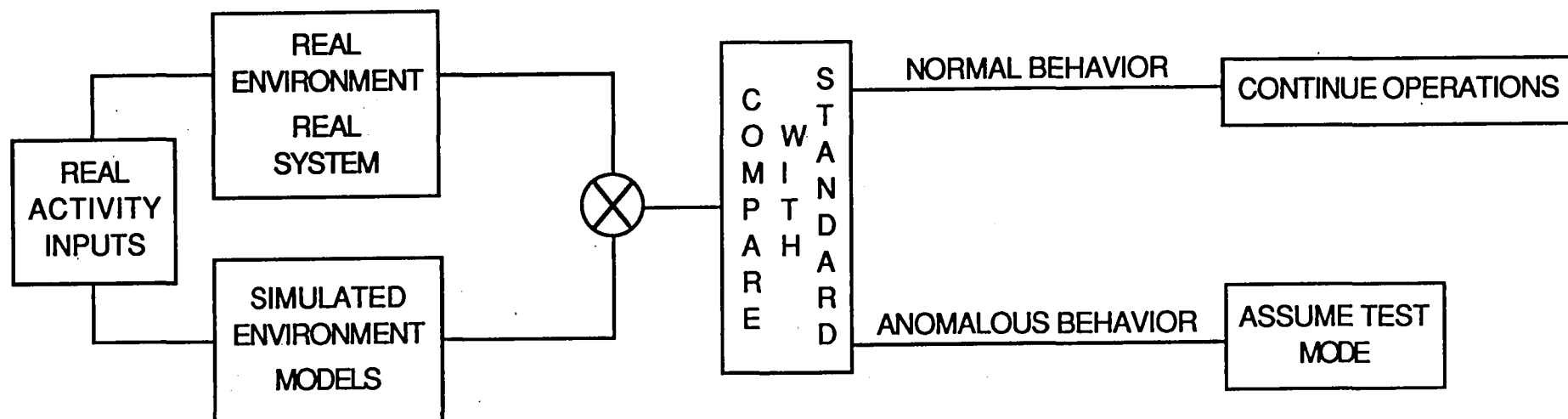
SIMULATION   ASSISTED SURVEILLANCE

SLIDE 15

THE ONBOARD CAPABILITIES MUST PROVIDE FOR APPROPRIATE
RESPONSES TO ONBOARD TESTING. THESE MUST INCLUDE THE
ABILITY TO EFFECTIVELY ANALYZE TEST RESULTS THEN TO TAKE
APPROPRIATE ACTION(S). IF THE RESULTS DON'T INDICATE A
PROBLEM, NORMAL OPERATIONS ARE MAINTAINED. IF THERE IS AN
INDICATED FAULT OR FAILURE ADDITIONAL TESTING MUST BE
DONE, FIRST TO RULE OUT "FALSE ALARMS" THEN TO DERIVE A
PROPER SET OF DIAGNOSTICS. SHOULD IT BE A FALSE ALARM,
NORMAL OPERATIONS ARE RESUMED WITH INCREASED
SURVEILLANCE OF THE SUSPECTED TEST SUBJECT OTHERWISE
APPROPRIATE CORRECTIVE ACTION(S) ARE TAKEN (RM SWITCHOVER,
WORK-AROUND RECONFIGURATION, REPAIR/REPLACEMENT). IF THE
TEST RESULTS INDICATE ONLY PERFORMANCE DEGRADATION, NOT
FAULT/FAILURE, THEN ACTIONS TO COUNTER THE PERFORMANCE
DEGRADATION ARE IN ORDER. THESE MAY BE ADJUSTMENTS OF
SYSTEM CONTROLS OR ACTIVITY SCHEDULES OR THEY MAY BE OF A
DIFFERENT NATURE, BUT MUST BE DIRECTED AT RESTORING THE
NOMINAL PERFORMANCE CAPABILITY. FOLLOWING ANY
CORRECTIVE ACTION, IT MUST BE VERIFIED TO BE COMPLETE AND
PROPER BEFORE ITS SUBJECT IS RESTORED TO NORMAL OPERATIONS.

SLIDE 15
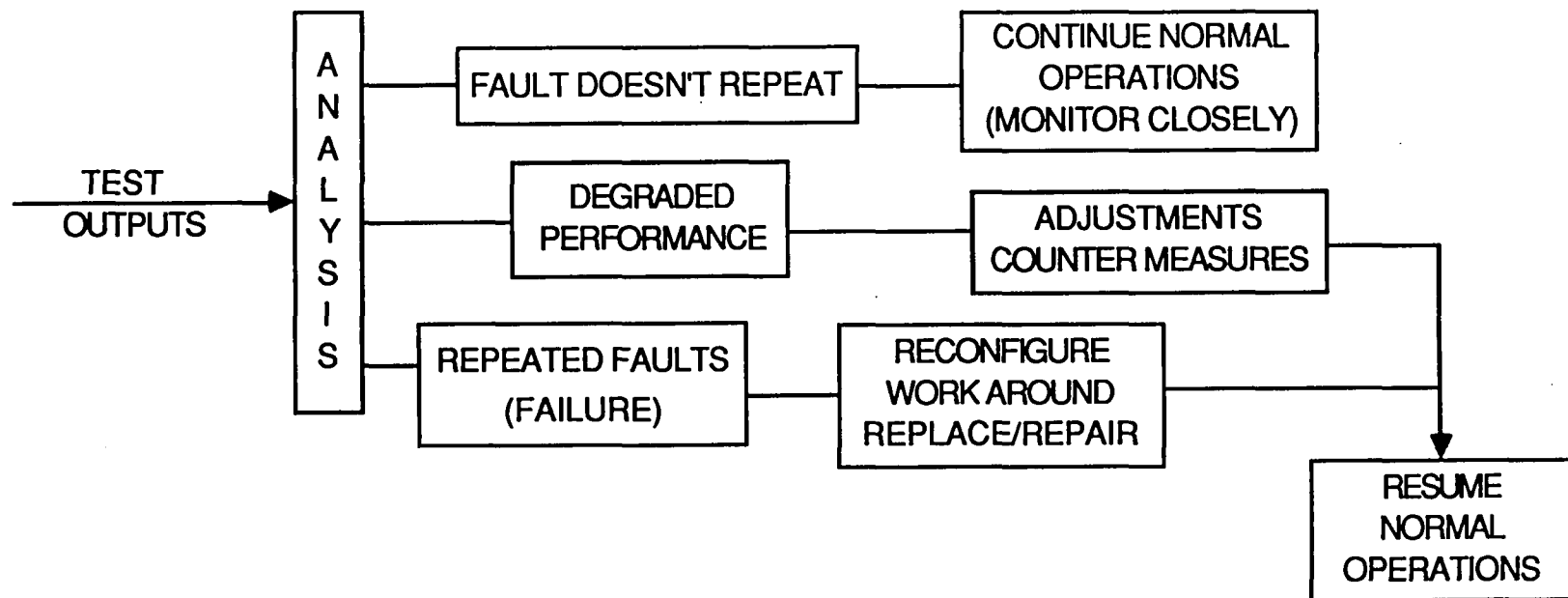
TEST RESPONSE/POST TEST ACTIVITIES

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An Overview of MCC and its Research

Dr. Stephen F. Lundstrom

Consultant

PARSA

(415)   723-0140

Consulting Associate Professor, Electrical Engineering

Computer Systems Laboratory

Stanford University

Microelectronics and Computer Technology Corporation
(MCC)

The Microelectronics and Computer Technology Corporation is a cooperative enterprise whose mission is to strengthen and sustain America's competitiveness in information technologies. Their objective is excellence in meeting broad industry needs through application-driven research, development and timely deployment of innovative technology.

MCC was chartered in August, 1982. Austin was selected as its headquarters in May, 1983 and research was underway by late that year.

Research Programs

Software Technology

To develop technology which will bring about extraordinary increases in software productivity, quality and life-cycle costs

VLSI/Computer Aided Design

To provide a means to greatly reduce the design time and improve the resulting design quality of complex micro-electronic circuits and systems

Packaging/Interconnect

To improve shareholder competitiveness in electronic manufacturing

Electronic Applications of High Temperature Superconductors

To understand the implications and potential impact of newly discovered superconductivity materials to electronics

Advanced Computing Technology

To develop technologies that will allow MCC shareholders and their customers to design very complex knowledge-based systems for any enterprise that is centered on information

MCC ORGANIZATION & STAFFING

287

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                    ┌─────────────────────┐
                    │ BOARD OF DIRECTORS  │
                    └─────────────────────┘
                               │
                    ┌─────────────────────┐
                    │    CEO & CHAIRMAN   │
                    └─────────────────────┘
                               │
        ┌──────────────┬───────┴───────┬──────────────┐
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| SOFTWARE TECHNOLOGY VICE PRESIDENT | VLSI / CAD VICE PRESIDENT | PACKAGING/ INTERCONNECT VICE PRESIDENT | ADVANCED COMPUTING TECHNOLOGY VICE PRESIDENT |

HIGH TEMPERATURE SUPERCONDUCTIVITY

TOTAL EMPLOYEES :   400 +
GRADUATE STUDENTS : 100 +
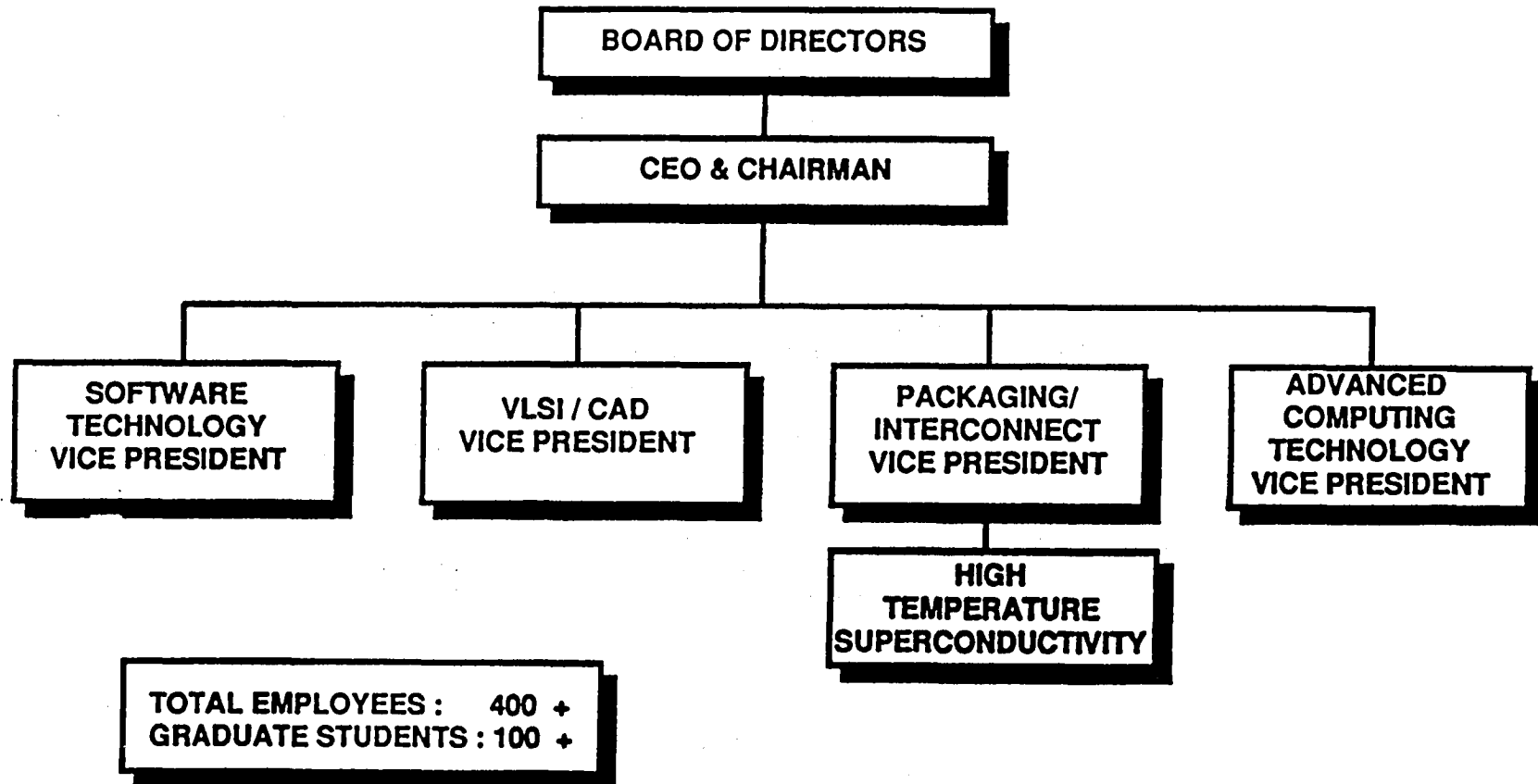
MCC Governance

Board of Directors

> One director from each of the shareholder companies. The board sets broad policy and meets regularly to consider important new strategic directions.

Technical Advisory Board

> One senior technical advisor or manager from each of the shareholder companies. The TAB reviews the general technical progress of MCC and identifies new and emerging directions which should be considered for new programs. Provides advice to the CEO on technical issues.

Program Technical Advisory Board

> Each of the research programs has an associated Program Technical Advisory Board which consists of members from each of the companies who participate in sponsoring the research in that program. This board monitors progress of the program and recommends technical strategy with respect to the directions of the program.

Program / Project Technical Panels

> Panels associated with each research program conduct detailed reviews of research progress and assist in identifying technology transfer opportunities in the participant organizations.

MCC GOVERNANCE

289

C-4

SHAREHOLDERS

MCC shareholders each own one share of stock in MCC, participate on the Board of Directors, and in at least one of the research programs. Participation in a research program involves sharing research costs with the others who are also participating, providing at least one researcher as a program liaison or assignee (who work as Members of the Technical Staff or in management positions, depending on their qualifications), and closely following the research progress in order to transfer technology back to the shareholder organization as quickly as possible. Shareholder participants have paid-up licenses for use of the technology developed in the programs in which they participate. They have general knowledge of activities in other programs (through the TAB.)

Shareholders

Advanced Micro Devices
Bellcore
Boeing
Cadence Systems
Control Data
Digital Equipment
Eastman Kodak
General Electric
Harris Corporation
Hewlett-Packard
Honeywell
Hughes/GM
Lockheed
Martin Marietta
Motorola
National Semiconductor
NCR Corporation
Rockwell International
Westinghouse
3m Corporation

ASSOCIATES

The MCC Associates Program offers a unique opportunity for U.S. and Canadian firms and organizations to participate in the MCC effort short of full-fledged equity participation. The Associates become part of the MCC community of world-class researchers, high technology corporations and supporting organizations committed to maintaining North American competitiveness in the global technology marketplace. For a modest participation fee, the Associates are kept abreast of progress in the MCC research programs and global technology developments. Associates may participate as non-equity participants in any of the research programs. The Associates Program opens the MCC effort to as many other organizations as possible in a pro-competition, pro-cooperation spirit.

MCC Associates membership offers qualification to join the MCC research programs as a non-equity participant. MCC is being restructured to allow more selective and lower cost ways of participating in their research. The basic differences between Shareholders and Associates are the Shareholders have governance rights over MCC and receive distributions of royalty income from third-party technology licensing. Associates have limited governance rights only for those projects in which they have elected to participate. Specific rights to technology for both Shareholders and Associates are detailed in the Research and Development Agreement for each program or project.

MCC Associates are invited to two or three seminars a year - designed specifically for the Associates - for a detailed look at progress in the MCC Technical Programs. These events provide an excellent opportunity to meet the researchers for a more in-depth assessment of the technology. Special meetings with researchers can be arranged from time to time.

MCC Associates have access to all proprietary technology monitoring and forecasting products of the MCC International Liaison Office. The ILO produces a highly-regarded monthly Newsletter on foreign technology developments, maintains an on-line database on foreign technology, writes occasional detailed technical reports on particular foreign technologies of interest and translates a large volume of Japanese-language technical papers from its unique database of Japanese technical literature. The ILO is in frequent contact with MCC Shareholders and Associates to answer their specific questions. The ILO can save an Associate a substantial part of the overhead of monitoring foreign technologies or advise Associates on how to establish their own monitoring programs. The ILO is also sponsoring a technology forecasting program, focussing on user needs for technology 5 to 10 years out.

Associates

Allied-Signal, Inc.
Apple Computer
Dell Computer Corporation
E.I. Dupont Denemours
E-Systems
General Dynamics
LTV Missiles and Electronics Group
Magnavox Government and Industrial Systems
Mitre
National Security Agency
Northrop
Olin Corporation
Power Electronics Application Center
Software Engineering Institute
Sun Microsystems
Symbolics
Texas Instruments
Tracor
TRW
United Technologies

PACKAGING / INTERCONNECT PROGRAM

Packaging/Interconnect refers to the process of assembling integrated circuits into systems and providing the systems with power and cooling. Recently, rapid advances in integrated circuit technology have caused many of today's packaging and interconnect techniques and processes to become obsolete. New technologies are needed to assure that the potential of complex circuits is realized.

The aim of MCC's Packaging/Interconnect (P/I) Program is to develop processes for yielding high performance at low cost, thus contributing to the competitiveness of MCC shareholders. The overall mission of the P/I Program is to provide U.S. semiconductor, materials, component and systems companies with superior technology through sharing of talent and material resources. The work includes the processing of ceramics and plastics, deposition of electrical conductors, development of bonding metallurgies, thermal management, laser-processing, and thin-film fabrication. It also includes the development of test techniques and tester technology.

The P/I Program will develop technology which is directed toward a **ten-million gate computer/signal processor** which can be packaged, assembled and tested at **a cost of less than $1,000.** This would double the performance of today's supercomputers at a small fraction of their cost. The technology will be completed and transferred to the shareholders by the end of 1992.

The Packaging/Interconnect Program is divided into four areas: a core and three satellites. Core research projects are longer range and intended to provide shareholders with a window on future technology, proving concepts and providing valuable know-how. Current satellites are:

- Bonding and Assembly Development
- Multi-Chip System Technology
- Interconnect Technology

MCC / Packaging/Interconnect

- Enable electronic packaging to keep pace with rapid advances in chip integration and speed
- Develop low cost, high performance and reliability, dual use technology
- Multi-chip modules provide improved performance at a lower cost and an increased reliability
- MCC P/I work in substrates, bonding, test and systems

Performance Potential of Multi-Chip Packaging

The goal of the Multi-Chip System Technology Satellite is to solve several problems related to the application of multi-chip packaging. Issues that are being addressed include heat removal, power handling and regulation capabilities, high performance connections, and testing.

Within this satellite, the Quick Turn Around Time (QTAT) interconnect project is providing design and process for generic or programmable interconnect techniques using a standard "blank." The blank is later customized to specific applications within 24 hours of design completion. MCC P/I is developing both substrate and board level QTAT techniques, so that most packaging levels within a system may be implemented more rapidly and at a lower cost. The project will allow wiring densities up to 500 lines per inch. This compares to current technologies which allow wiring densities of less than 100 lines per inch.

The satellite is conducting technology integration studies, is developing technology in a Chip on Substrate Test (COST) project which will verify that electrical objectives of the interconnect technology are met, and is developing liquid-cooled heat exchangers which can be integrated with MCC TAB (Tape Automated Bonding) and substrate technologies in a multi-chip module. The liquid-cooled heat exchangers will remove 50 watts of heat per square centimeter with low pressure and low flow requirements with either water or organic liquids. Novel air cooling technology which permits the removal of 30 watts of heat per square centimeter has already been developed.

Performance potential of Multi-Chip Packaging

- improve system performance, reliability and
  cost
- chip technologies are too costly
— don't solve performance and density
— do not address the major reliability factors
- reliability limiting parts
— interconnection and packaging
— substantial improvement possible
— high density chip-on-board
— centimetres to mm.

297

CONCLUSIONS (P&I)

Packaging and Interconnect continues to be the main gating factor to achieving cost effective systems. Packaging and Interconnect technology is the primary limitation to speed, reliability, testability, and affordability. Therefore, MCC believes that P&I will be a dominant force in the 1990's which will contribute to the competitiveness of the sponsors of the P&I program. The MCC P&I program will continue to emphasize multichip modules with vertically integrated R&D which addresses the issues of design, fabrication, assembly and test. The result is expected to be computers that are fast (3 ns cycle time), large (10 million gate) and low cost ($5000.)

Conclusions

- PI continues to be main gating factor to cost effective systems
- PI limits speed, reliability, testability, and affordability
- It will be dominant force in the 1990's
- MCC approach emphasizes MCM
  — Vertically Integrated R&D to participants
  — Design, Fabrication, Assembly & Test
  — Computers that are fast (3 ns cycle time), large (10 million gate) and low cost ($5000)

THE MCC CAD PROGRAM

GOALS

The complexity of integrated circuits (ICs) continues to increase by as much as 50 percent per year. By the mid-1990s, complex ICs will contain upwards of 10 million devices and the resulting systems will be at least an order of magnitude more complex. This trend continues to affect chip and system makers alike. Electronic system manufacturers and IC suppliers are now designing ICs that have rapidly decreasing line widths and employ increasingly complex processes. In order to remain competitive in the next decade, these companies demand a shorter time-to-market for new products and require lower relative design costs than they have today. Breakthroughs in both CAD application tools and systems are required.

The MCC CAD Program performs state-of-the-art research into CAD tools and systems that will deal effectively with these technology challenges. The program provides computer-aided design tools and an integrating CAD system framework to its participants, which will help them resolve key design time, quality, and resource bottlenecks in the design of complex integrated circuits and electronic systems.

To carry out this objective, the CAD Program identifies targets of opportunity for its research and development (R&D) projects. The CAD Program only undertakes R&D efforts in which CAD technology from other sources available to the participant (CAD vendors, universities, internal participant projects) is projected to be inadequate. MCC monitors new CAD developments in the commercial arena and within universities to target opportunities. The CAD Program also acquires and evaluates the most current commercial tools. MCC CAD constantly evaluates new and ongoing R&D projects from other organizations and monitors its own projects to ensure that at least one of the following criteria is met at the time the company delivers software to its participants: (1) The CAD tool or system to be produced will be functionally superior to software available from other sources to reduce design time and/or cost, or (2) The CAD tool or system will be more cost effective to the MCC CAD participants than other sources of that technology.

THE MCC CAD PROGRAM
GOALS

- Develop a "<u>best in class</u>" CAD framework that facilitates development and execution of native tools while providing easy integration of external tools.

- Play a <u>leadership</u> role in the creation of <u>industry standards</u> for design data representation, tool management and communication, and other important CAD framework issues.

- Deliver <u>advanced CAD tools</u> in areas that will advance the state of design and are <u>not adequately addressed by commercial efforts.</u>

301

THE MCC CAD PROGRAM

Short Term Plans

MCC organizes its CAD Program resources as a Core and four Satellites: System Design, Digital Design, Test Design and Physical Design. Each area has its defined targets of opportunity that result in short and long term goals. The responsibilities of the Core include development of a "best-in-class" CAD framework, coordination of technology tracking and forecasting activities, and code release preparation for all CAD Program deliverables. In addition, a system engineering function integrates the framework and individual application tools.

Each of the four satellites concentrates on a specific range of tasks in the design process. The System Design satellite addresses high-level problems of designing multi-chip systems, starting from informal requirements or specifications and evolving to component design specifications.

Projects in the Digital Design satellite help create and verify gate-level design, given a system architecture as an input. Current projects in this satellite include: VHDL analysis and simulation tools, hierarchical timing analysis, and mathematical verification of design correctness.

Projects in the Physical Design satellite take a functionally-verified, gate-level description as input and create a mask-level IC design. The satellite continues its work on the C Module Editor (CME) tool, a symbolic IC layout system that employs a unique graphical programming paradigm and a powerful compaction algorithm. The CME is design-rule independent. The Physical Design satellite is also addressing the layout synthesis problem.

The Test satellite focuses on the need to rapidly generate tests for complex systems. Current projects include a comprehensive fault simulation/automatic test pattern generation (FS-ATPG) tool that incorporates key new algorithms to handle high complexity, and the Testability Insertion Guidance ExpeRt (TIGER), a knowledge-based expert system that guides the designer to improve a design's testability at the register-transfer level and above.

THE MCC CAD PROGRAM

SHORT TERM PLANS

DIGITAL

- VHDL simulation
  - Partial implementation
  - Full IEEE 1076 implementation
  - Debugging capability
- Hierarchical timing analysis & verification

PHYSICAL

- Cell design
  - Module generation
  - Applications of reusability

SYSTEM

- Research area
- System Modeling

FRAMEWORK

- Develop framework plan
- Implement initial framework
- Initialize CAD Framework Lab

TEST

- ATPG/ fault simulator
- TIGER - high level testability analyzer and synthesizer

CORE

- System Engineering
- Technology Transfer
- Shareholder Relations

303

SOFTWARE TECHNOLOGY PROGRAM

Most large, complex computer systems of the future will be **distributed systems.** In a widely distributed network of hundreds - even thousands - of low-cost, high-performance individual workstations, data can be shared, available, and correct, when and where it is needed. These systems will offer two dramatic benefits:

- **Teamwork and cooperation.** The distributed network will provide tools that greatly assist users in planning, coordinating, and managing resources - including human resources.

- **Reliability.** The effective replication and management of shared data will ensure that a breakdown in one part of the distributed network does not significantly interfere with the smooth functioning of another.

Other work in Software Technology focused on **downstream** activities. Compilers were developed in the 1960s. Structured programming was the focus of the 1970s. Programing environments was the new major issue of the 1980s.

In creating **Leonardo,** STP is focusing its efforts on the *upstream* of the software systems design process. Upstream activities encompass the period from a project's "fuzzy requirements" phase, through its design, to the point at which formal specifications can emerge.

These early, creative phases of design offer great leverage in ensuring a given project's eventual success. Downstream outcomes are, in fact, determined by upstream decision - decisions about customer needs and design assumptions, about resources and components, and about how the system's vision matches its requirements. Indeed, study after study reveals that *over half* of the development effort typically is spent on these and other upstream activities.

Yet currently, the upstream remains unquantified, unarticulated, and poorly addressed by technology. Management and technical tasks are seldom coordinated; communication is haphazard and unfocused. The price, in both human and economic terms, is this: fixing design defects and adding functionality currently account for *over 80 percent* of the cost of maintaining a system once it is in operation.

Leonardo computer-aids the upstream, so that everybody involved in a complex system's design - developers, managers, and targeted users alike - can function as a coordinated, focused team. This unique environment promises extraordinary gains in the productivity of the designers and in the quality of the systems they produce.

Software Technology Evolution

UPSTREAM | DOWNSTREAM

Fuzzy Req'ts

90's — 80's — 70's — 60's — 50's

Manual

Machine-aided

Leonardo

Programming Environments e.g., Ada APSE

Structured Programming

Com-pilers

Bits & Bytes
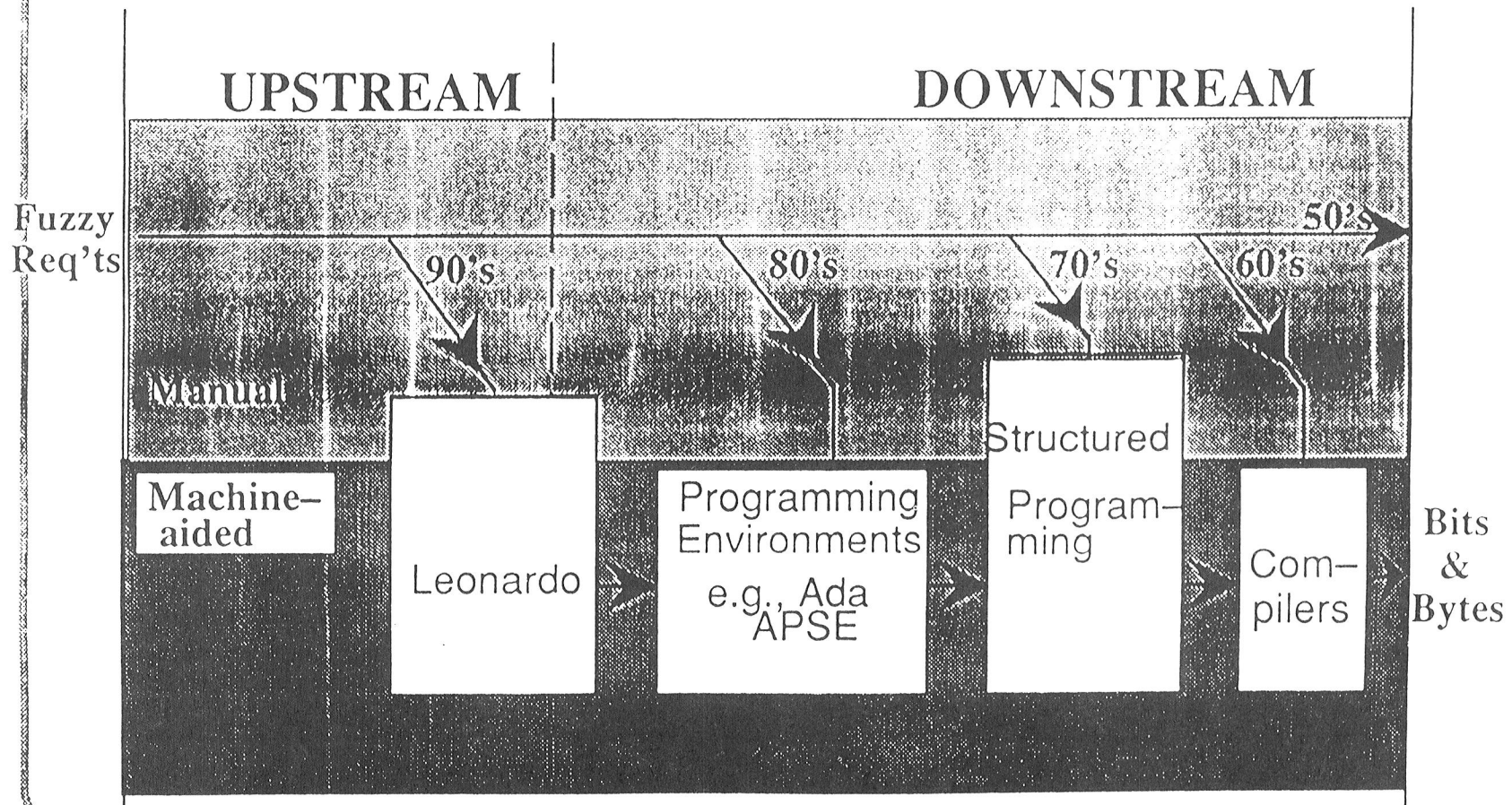
THE LEONARDO VISION

• COORDINATING THE DESIGN TEAM

The group design of a typical, large complex software system requires the simultaneous efforts of many specialists working cooperatively. Like the system it is designing, this team is often widely distributed in space and time. Like the individual computer processes being created to drive the emerging system, the team must function smoothly.

In most large project teams, the issue of coordination tends to be minimized or ignored. Poor communication - both between processes and between members of the design team - is widely acknowledged to cause rework and inefficiency, and chasing new code-writing technology has not worked as the remedy of choice. The problem is this: until now, there have been no conceptual models of systems design coordination, much less the tools for achieving that coordination. Major work is underway at STP for ensuring that *Leonardo* provides both. Powerful hypermedia tools which represent data in an associative, rather than a linear, way - in graphical networks of nodes and links - have been developed. The data can be text, graphics, or synthesized speech. *Leonardo* includes tools which support the notions of *process teams* and *multiple-party process interactions.* Visual environments are available to edit the coordination scripts which organize the multi-design interactions in the process that an organization goes through to produce a large, complex software system. Multi-designer interactions are organized by allowing for explicitly written, graphically represented descriptions of the design process. Each member's "electronic desk" serves as an interface to the overall process and to the status of the member's current role in the organization. A graphical tools which allow design argumentation into a hypermedia network that can be constructed, analyzed, and edited by the design team members have been developed.

SUPPORTING THE SOFTWARE DESIGNER

The software design process continues to be poorly understood - particularly the process of designing large, complex systems in project teams. Little empirical research has examined the cognitive foundation for this process or pinpointed specific components. No theories formally describe or organize the information used by designers. Consequently, information reused across the design process typically remains unidentified and is often redeveloped during a single project. STP conducts **empirical studies** to determine what design tasks must be supported in order for *Leonardo* to have maximum value for its shareholders. A major focus is **Computer-Aided Design Deliberation and Reuse.** One project is focusing on how a designer makes and records design decisions as the project progresses from requirements to code. A graphically oriented technology has been created to capture and represent information about a project's history and about the dependencies between system components. A **reuse** system provides the designer with two reusable libraries - a library of abstract design schemas and one of abstract algorithms. A design schema is the way in which early design structures are captured. The designer can pull up, edit and refine a design schema to pin down precise elements of the target system's architecture. Once these elements are defined, the *Leonardo* designer will use the abstract algorithm library to customize the abstract designs into code.

MCC Software Technology Program

Organize
Prototype
Integrate
Leonardo

85   86–87   88–90   91-92

The Leonardo Vision

- Integrated System Design Environment

    –Upstream Emphasis (Symbolic Comp.)

    –Prototyping & Simulation

- Mission: Extraordinary Productivity& Quality

- Long Range/High Risk Research

- Team Focus

- Visual/Human Orientation to Tools

- Distributed/Embedded Target Systems

- Reuse of Designs

ADVANCED COMPUTING TECHNOLOGY (ACT)
Projects and Organization

Organization

Shareholders and Associates can choose to participate in each of the programs shown as shaded blocks in the figure. Recently, the Neural Nets program has been moved to the same level as the HI Lab in the organization.

OODS (Object Oriented and Distributed Systems) LAB

The ODBS project provides rich database software capabilities to both object oriented programming environments and data-intensive, symbolic applications, such as CAD/CAM, artificial intelligence, and office information systems. The ODBS project has already delivered ORION, a prototype of an object oriented database system on a single workstation. This system is being extended into a distributed database. In addition, the group is working to design and demonstrate a high-performance system architecture to support the concurrent object model by exploiting parallel processing opportunities.

OPTICS

The optics group is conducting research into the application of optics technology in high performance computing systems. These studies are currently focused in high performance interconnects for highly parallel systems and a high capacity, low latency holographic storage technology (with no moving parts.)

AI LAB

This group is generating a very large knowledgebase called CYC, that contains a foundation of general (encyclopedic) and common-sense knowledge. The work in Reasoning Architectures is creating expert system shells that provide rich development facilities for the language as well as efficient run-time environments. The Knowledge Based Natural Language group is working to extend computer interaction and understanding capabilities to include unrestricted natural language.

DEDUCTIVE COMPUTING

This group has designed and implemented a Logic Data Language (LDL). This is a logic-based language intended for data and knowledge intensive applications. The LDL system combines the expressive power and the supporting technologies of logic programming and relational databases. Future extensions will support richer knowledge representation primitives and constraint-based programming.

HUMAN INTERFACE

The Human Interface Lab is focused on dramatically improving the *usability* of complex systems. The mission of the lab is to develop the scientific and technological foundations for principled and efficient construction of effective interfaces. HITS, a Human Interface Tool Suite, provides tools to support the design of intelligent, multimedia interfaces.

ACT PROJECTS & ORGANIZATION

ADVANCED COMPUTING TECHNOLOGY RESEARCH PROJECTS

OODS LAB
- OBJ.-ORIENTED DBMS
- SHARED HETEROGEN. DB
- OBJ.-ORIENTED CONC. SYST.

OPTICS
- HOLOGRAPHIC STORAGE
- OPTICS IN COMP. ARCH.
- OPTICAL CROSSBAR
- OPTICAL NEURAL NETS

AI LAB
- CYC CONCENSUS KB
- REASONING ARCH.
- NATURAL LANGUAGE

DEDUCTIVE COMPUTING
- LOGIC DATA LANGUAGE
- SW FORMAL METHODS

HI LAB
- HUMAN INTERFACE
- NEURAL NETS
- EXTRACT DATA CONVERSION

ES-KIT
- HARDWARE PROTOTYPING
- C++ // SW ENVIRONMENT

TRANSACTION PROCESSING

NOTE : PROJECTS SHOWN IN SHADOW BOXES ARE SEPARATELY FUNDABLE

DATA CONVERSION (EXTRACT)
Project Focus

The EXTRACT project has developed tools which allow data conversion or migration from one or more databases and file structures into others. The user describes the databases or file structures to be connected and the data to be handled with a formal notation. The system then automatically generates code which connects the EXTRACT system to those databases and file structures. The EXTRACT system includes a temporary database storage and automatic management of the movement of data from one place to another. The work of this project is nearly completed.

DATA CONVERSION (EXTRACT)
PROJECT FOCUS

ALLOW DATA CONVERSION / MIGRATION FROM ONE OR MORE DATABASES / FILE STRUCTURES INTO OTHERS

OBJECT-ORIENTED DATABASES

RECORD-ORIENTED DATABASES

RELATIONAL DATABASES

NAVIGATIONAL DATABASES

EXTRACT

TEMPORARY DATABASE STORAGE	INTERNAL DATABASE
	SYSTEM INFORMATION & DATA STRUCTURE

ASCII DATA FILES

DATA EXCHANGE LANGUAGE DATABASES
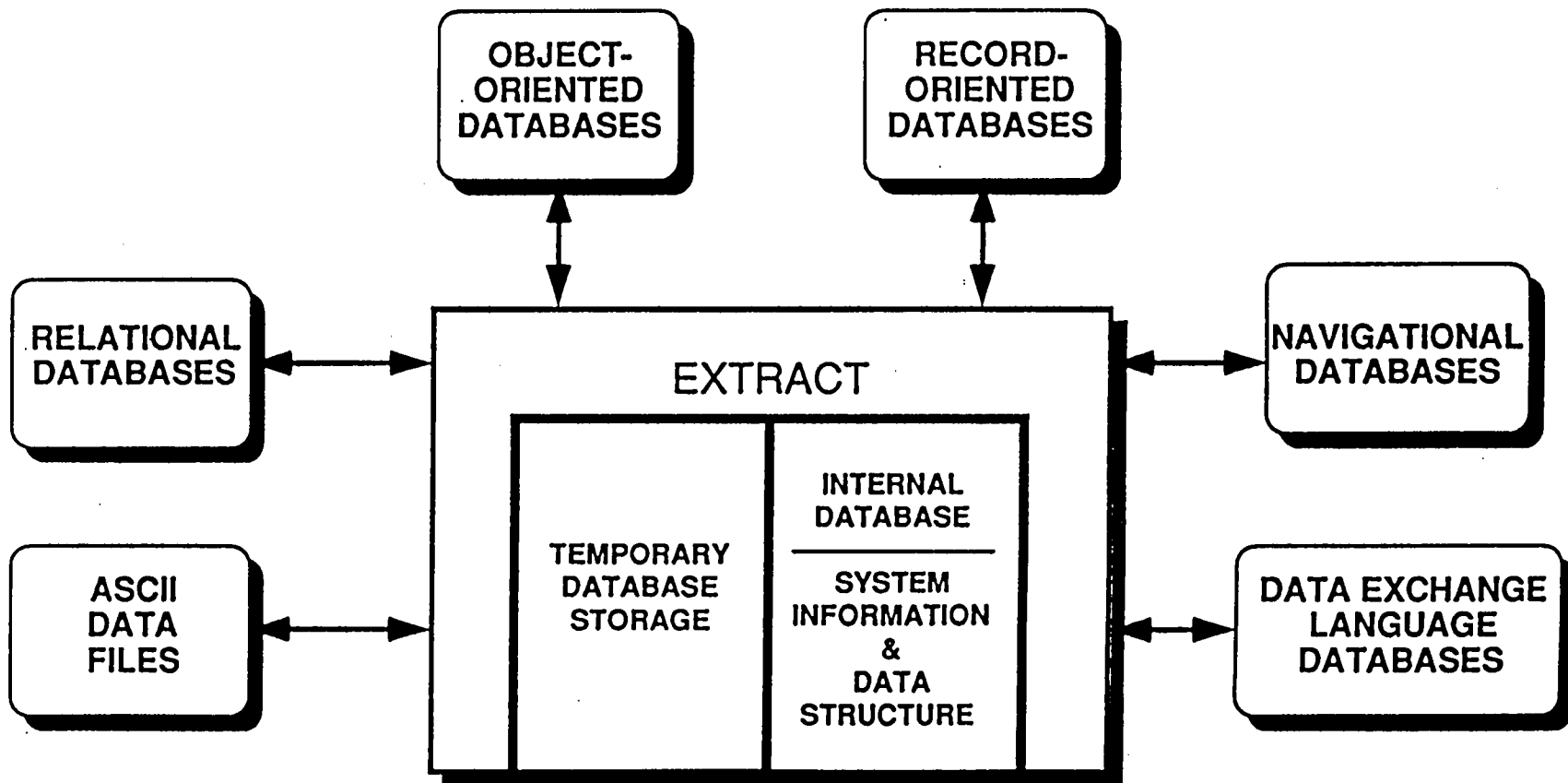
PARALLEL SYSTEMS PROTOTYPING (ES-KIT)

The Experimental System Builders Kit (ES-KIT) group is developing technologies which allow rapid, low-cost prototyping of experimental high-performance computing systems. The ES-KIT is a set of compatible hardware and software technologies that can be used to very quickly construct unique high-performance systems - parallel systems in particular. The hardware modules include processor, memory, hard disk, message-passing communications, and instrumentation modules. The initial modules are Motorola 88000 based. New modules based on the Intel i860 are under development. The software support includes a parallel C++ compiler, UNIX operating system modules which connect the hardware modules to the UNIX environment in a workstation host, software instrumentation insertion support, and tools to support the presentation of data collected from builtin hardware and software instrumentation. The work of this group has been sponsored by DARPA and is currently being distributed to other researchers around the United States for use in a wide variety of projects.

PARALLEL SYSTEMS PROTOTYPING (ES-KIT)

ANTICIPATE ARCHITECTURAL AND IMPLEMENTATION NEEDS OF EMERGING COMPLEX,
PARALLEL SYSTEMS AND DEVELOP MODULAR BUILDING BLOCKS & TOOLS THAT
SUPPORT FAST AND AFFORDABLE PROTOTYPING OF THESE SYSTEMS

E S   R E S E A R C H

MODULAR REUSABLE HARDWARE

MODULAR PORTABLE SYSTEM SOFTWARE

DEMONSTRATION/ TEST APPLICATIONS

◆ BENEFIT ◆

FAST PROTOTYPING

50 - 75 % LESS TIME PARALLEL/ SCALABLE ARCHITECURES DISTRIBUTED ARCHITECTURES

DRAMATIC REDUCTIONS IN THE TIME AND COST OF COMPLEX SYSTEM PROTOTYPING REQUIRES
A BROAD SPECTRUM OF REUSABLE MODULES WHICH ARE RELATIVELY INSENSITIVE TO OVERALL
ARCHITECTURES. SW IS OBJECT-ORIENTED & INITIAL HW MODULES ARE MOTOROLA 88000 BASED.

313

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314

Environmental Control and Life Support System

Level III

Subsystem Presentation

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316

Environmental Control and Life Support System

Charles Ray

Alan Adams

Marshall Space Flight Center

Technology for Space Station Evolution Workshop
January 16-19, 1990
Dallas, Texas

N93-27718

ECLSS SUBSYSTEM FUNCTIONS

THE ECLSS IS DIVIDED INTO SIX SUBSYSTEMS: TEMPERATURE AND HUMIDITY CONTROL (THC),

ATMOSPHERE CONTROL AND AND SUPPLY (ACS), ATMOSPHERE REVITALIZATION (AR), FIRE DETECTION

AND SUPPRESSION (FDS),WATER RECOVERY MANAGEMENT (WRM) AND WASTE MANAGEMENT (WM).

THIS CHART PROVIDES A LISTING OF THE MAJOR FUNCTIONS OF EACH SUBSYSTEM.

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ECLSS Subsystem Functions

```
                    ┌─────────────┐
                    │    ECLSS    │
                    └─────────────┘
```

Temperature And Humidity Control (THC)	Atmosphere Control And Supply (ACS)	Atmosphere Revitalization (AR)	Fire Detection And Suppression (FDS)	Water Recovery Management (WRM)	Waste Management (WM)
• Cabin Temp/ Humidity Control • Avionics Cooling • Process Air • Refrigerator/ Freezer*	• Pressure Control • O_2/N_2 Composition Control/ Monitor • Gas Storage • Vent And Relief	• CO_2 Removal • Trace Contam Control • Trace Contam Monitor • O_2 Generation • CO_2 Reduction	• Fire Detection • Suppressant Stowage • Suppressant Distribution	• Potable Recovery • Hygiene Recovery • Urine Recovery • Water Quality Monitor • Process Control Monitor	• Fecal Processing • Urine Collection

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM

THE ECLSS CONSISTS OF NON-REGENERABLE AND REGENERABLE HARDWARE. THE NON-REGENERABLE HARDWARE IS FOUND MAINLY IN FOUR OF THE MAJOR SUBSYSTEMS: ATMOSPHERE CONTROL AND SUPPLY (ACS), TEMPERATURE AND HUMIDITY CONTROL (THC), FIRE DETECTION AND SUPPRESSION (FDS) AND WASTE MANAGEMENT (WM). THE REGENERABLE HARDWARE, WHICH POSES THE GREATEST TECHNOLOGICAL CHALLENGE, IS FOUND IN THE ATMOSPHERE REVITALIZATION (AR) AND THE WATER RECOVERY AND MANAGEMENT (WRM) SUBSYSTEMS. THE REGENERABLE SYSTEMS PROVIDE A MEANS OF GENERATING OXYGEN, REMOVING/REDUCING CARBON DIOXIDE AND RECLAIMING WATER FOR USE BY THE CREW WHICH MINIMIZES THE SPACE STATION LOGISTICS BURDEN.

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Environmental Control And Life Support System

Non - Regenerable

Regenerable

```
Atmosphere Control
And Supply (ACS)
Subsystem
```
O2   N2

```
Temperature and
Humidity Control
(THC) Subsystem
```

```
Atmosphere
Revitalization (ARS)
Subsystem
```

O2

Air

Air

H_2O H_2O

```
Fire (FDS) Detection
And Suppression
Subsystem
```

H_2O

```
Water Recovery and
Management (WRM)
Subsystem
```

H_2O FMS

H_2O FMS

Urine

```
Waster Management
(WM) Subsystem
```

H_2O
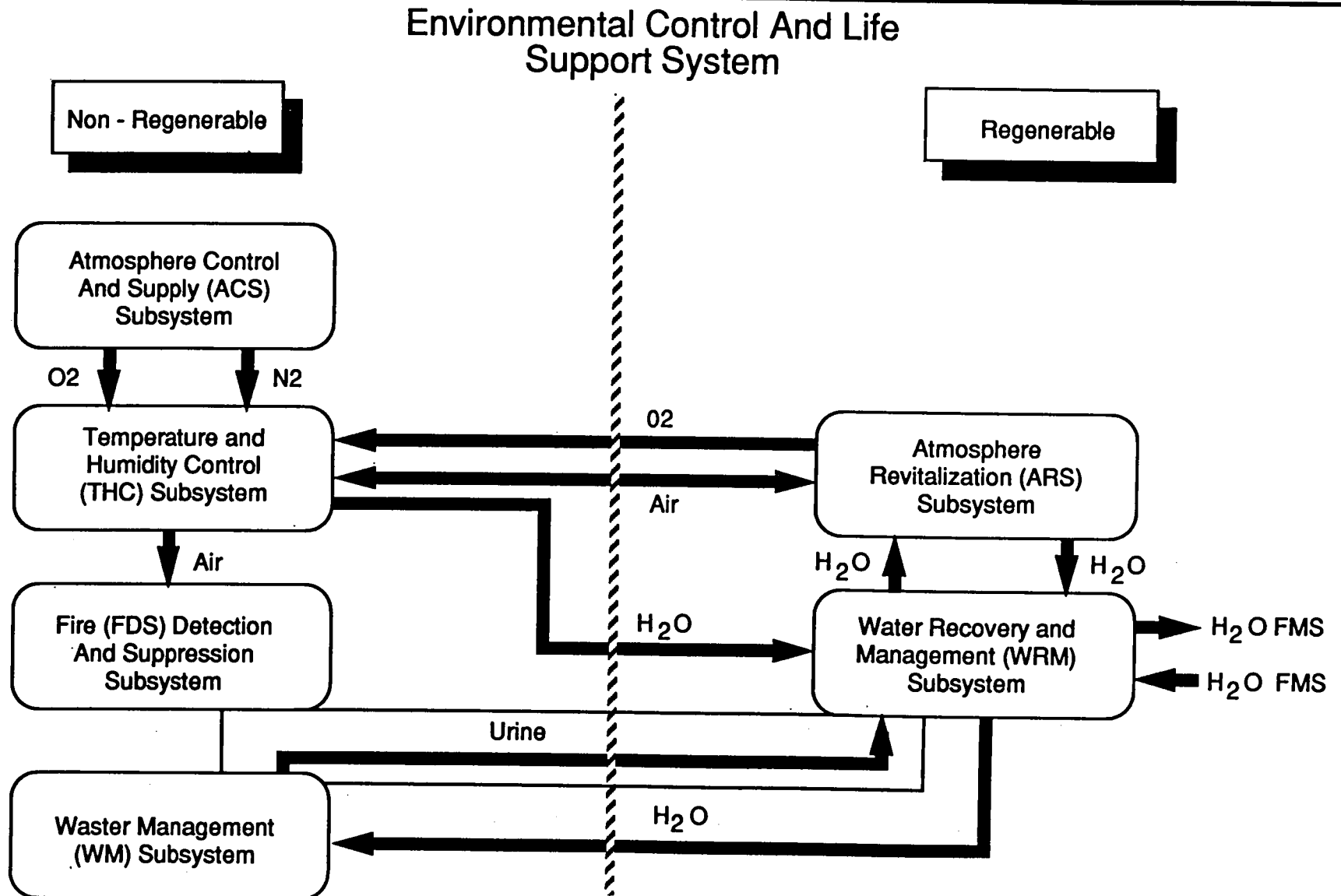
ECLSS DISTRIBUTED SYSTEM

THE ECLSS IS TRULY A DISTRIBUTED SYSTEM. ECLSS HARDWARE/FUNCTION IS FOUND IN EVERY SPACE STATION ELEMENT. ALTHOUGH THE MAJOR COMPONENTS OF THE ECLSS ARE CONCENTRATED IN THE U.S. HABITATION AND LABORATORY MODULES, OTHER ECLSS FUNCTIONS SUCH AS ACS, THC, FDS CAN BE FOUND IN THE NODES, AIRLOCK AND LOGISTICS MODULES.

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ECLSS Distributed System
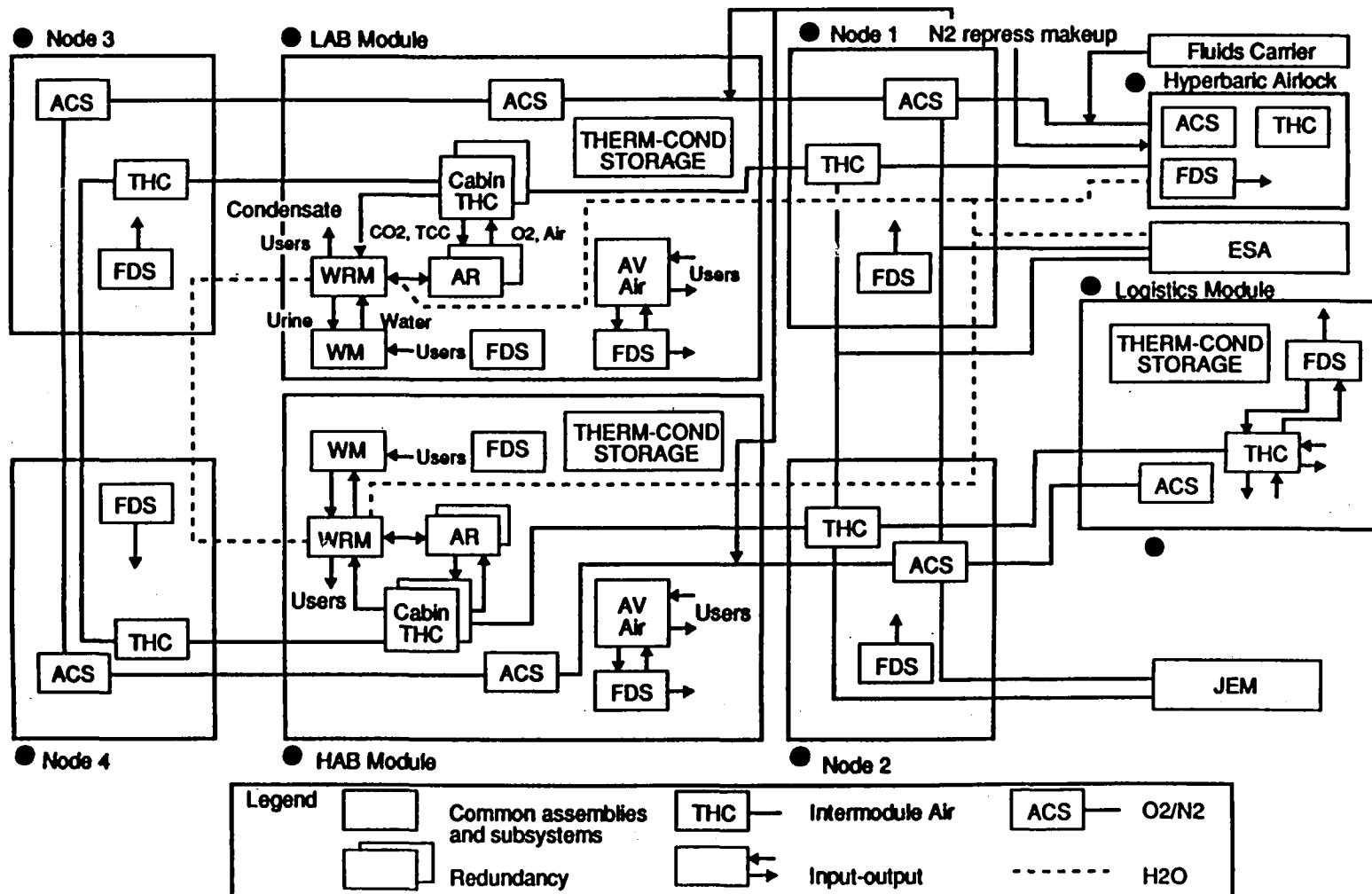
ECLSS DESIGN FEATURES

THIS CHART PROVIDES A SUMMARY OF THE MAJOR DESIGN FEATURES OF EACH ECLSS SUBSYSTEM.

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Design Features

- System
  - 4 Crewmen At PMC, 8 Crewmen At AC
  - Attached Module Services Provided By Distribution System

- Temperature And Humidity Control
  - Intermodule Process Air Provides CO_2 Removal O_2 Partial And Total Pressure Control For Station Pressurized Volume
  - Avionics Cooling Supplied To All Powered Racks In U.S. Modules
  - Redundant Assemblies In Hab And Lab

- Atmospheric Control And Supply
  - Oxygen And Nitrogen Distributed To All Pressurized Modules
  - Positive And Negative Relief Capability Provided In All U.S. Pressurized Modules

- Atmosphere Revitalization
  - Redundant Assemblies In Hab And Lab
  - Regenerable O_2 Generators, CO_2 Removal, CO_2 Reduction Units Located In Hab And Lab
  - Distribution System To Provide Monitoring Of Trace Contaminants In Any Pressurized Module

- Fire Detection And Suppression
  - FDS Functions Provided To All Powered Racks In U.S. Modules
  - Portable Extinguisher To Backup Central Suppressant Storage

- Water Recovery Management
  - Separated Potable And Hygiene Water Subsystems
  - Potable And Hygiene Processors In Hab And Lab Integrated By Distribution Systems
  - Urine Processed To Hygiene Water

- Waste Management
  - Crew Exposure To Fecal Material Precluded

325

ECLSS FUNCTIONAL DISTRIBUTION

ECLSS HARDWARE IS LOCATED IN VIRTUALLY EVERY SPACE STATION ELEMENT. HOWEVER, SOME OF THE ECLSS FUNCTIONS ARE PROVIDED TO SOME OF THE SPACE STATION ELEMENTS THROUGH NON-HARDWARE MEANS SUCH AS INTERMODULE VENTILATION AND SAMPLING LINES.

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ECLSS Functional Distribution

ECLSS Function	HAB	LAB	LOG	HAL	Node	JEM	ESA
Temperature/Humidity Control							
Air Temp Control	HW	HW	HW	HW	HW	HW	HW
Humidity Control	HW	HW	HW	HW	HW	HW	HW
Ventilation	HW	HW	HW	HW	HW	HW	HW
Avionics Cooling	HW	HW	HW	HW	HW	HW	HW
Refrigerator/Freezer	HW			HW			
Atmosphere Control/Supply							
O_2/N_2 Pressure Control	HW	HW	HW	HW	HW	HW	
Vent And Relief	HW	HW	HW	HW	HW	HW	HW
Monitoring	HW	HW	SL	HW	SL	HW	SL
O_2/N_2 Distribution	HW	HW	HW	HW	HW	HW	HW
Atmosphere Revitalization							
CO_2 Removal	HW	HW	IMV	HW	IMV	HW/IMV	IMV
CO_2 Reduction	HW	HW					
O_2 Generation	HW	HW					
Contaminant Control	HW	HW	IMV	IMV	IMV	IMV	IMV
Contaminant Monitoring	HW	HW	SL	SL	SL	SL	SL

HW – Hardware   IMV – Intermodule Ventilation   SL – Sampling Line

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ECLSS Functional Distribution (Continued)

ECLSS Function	HAB	LAB	LOG	HAL	Node	JEM	ESA
Fire Detection/Suppression	HW	HW	HW	HW	HW	HW	HW
Water Recovery/Management							
Potable H_2O Processing	HW	HW					
Hygiene H_2O Processing	HW	HW					
Urine Processing	HW	HW					
Distribution	HW	HW	HW	HW	HW	HW	HW
Waste Management							
Fecal Processing/Storage	HW	HW					
Return Waste Storage			HW				

HW – Hardware IMV – Intermodule Ventilation SL – Sampling Line

CARBON DIOXIDE REMOVAL

THIS CHART PRESENTS THE FUNCTIONAL DESCRIPTION OF THE CARBON DIOXIDE REMOVAL SUBSYSTEM
FOR THE SPACE STATION FREEDOM PROGRAM. PROVIDED ALSO IS A GENERAL SCHEMATIC DISPLAYING
THE PRIMARY INPUTS AND OUTPUTS OF THE UNIT.

330

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CO_2 Removal

Functional Description:

- Selectively Remove Carbon Dioxide Generated By The Crew's Metabolic Processes From The Cabin Atmosphere, Maintaining A Maximum pp CO_2 Limit As Shown Below:

Mode Of Operation	$ppCO_2$
Normal	3.0 mm Hg
90 Day Degraded	7.6 mm Hg
45 Day Emergency	12.0 mm Hg

- Concentrate The Removed CO_2 For Downstream Processing In The Carbon Dioxide Reduction System.
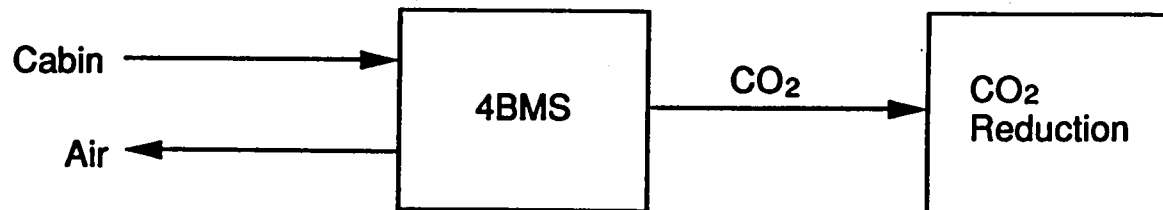
CARBON DIOXIDE REDUCTION

THIS CHART PRESENTS THE FUNCTIONAL DESCRIPTION OF THE CARBON DIOXIDE REDUCTION SUBSYSTEM

FOR THE SPACE STATION FREEDOM PROGRAM. PROVIDED ALSO IS A GENERAL SCHEMATIC DISPLAYING

THE PRIMARY INPUTS AND OUTPUTS OF THE UNIT.

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CO_2 Reduction

Functional Description:

- Reduce CO_2 To Form Solid Carbon By-Product And Potable Water
- CO_2 Is Fed From CO_2 Removal Device
- Processes At A 4-Man Load Under Normal Conditions And 8-Man Load Under Emergency Conditions.
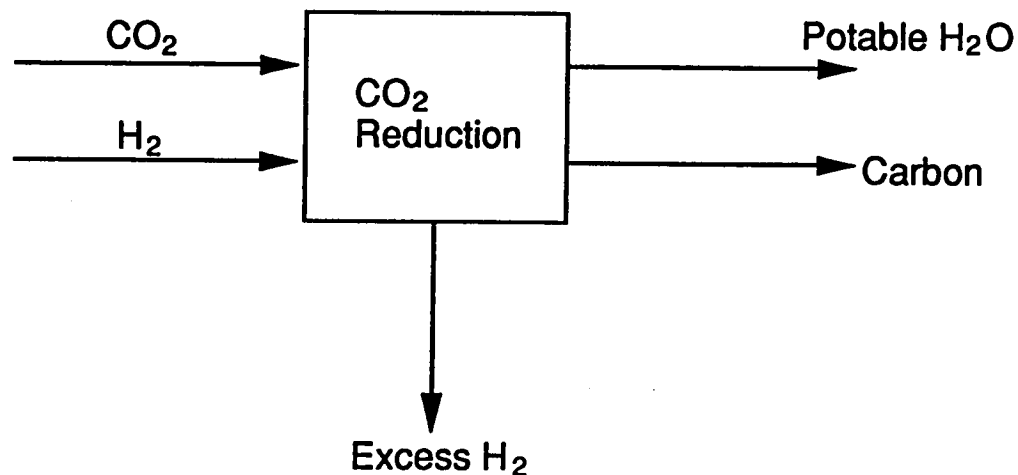
OXYGEN GENERATION

THIS CHART PRESENTS THE FUNCTIONAL DESCRIPTION OF THE OXYGEN GENERATION SUBSYSTEM FOR THE SPACE STATION FREEDOM PROGRAM. PROVIDED ALSO IS A GENERAL SCHEMATIC DISPLAYING THE PRIMARY INPUTS AND OUTPUTS OF THE UNIT.

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A Workshop

Oxygen Generation

FUNCTIONAL DESCRIPTION

- The OGA Produces Oxygen By Electrolyzing Processed Hygiene Water. Normal Production Is 9.08 lb-O2/Day; Emergency Condition 45 Day Production Is 15.75 lb-O2/Day.

- The Oxygen Is Delivered To The Cabin Ventilation System Or Stored For EVA.

- The Hydrogen By-Product Is Fed To The Carbon Dioxide Reduction System.

335
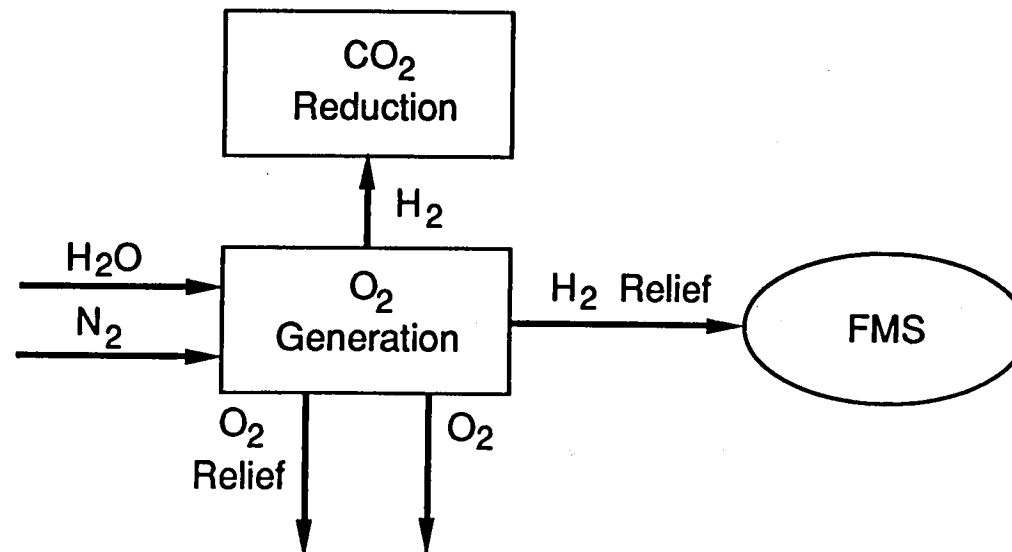
URINE PROCESSOR

THIS CHART PRESENTS THE FUNCTIONAL DESCRIPTION OF THE URINE PROCESSOR SUBSYSTEM FOR THE

SPACE STATION FREEDOM PROGRAM. PROVIDED ALSO IS A GENERAL SCHEMATIC DISPLAYING THE

PRIMARY INPUTS AND OUTPUTS OF THE UNIT.

Technology For Space Station Evolution - A Workshop

Urine Processor

Functional Description:

- Recover Hygiene Water From Human Urine

- Processing Rate Is 50-70 Lbs/Man/Day

```
Urine  →  ┌──────────────┐  Product   ┌──────────────┐  Hygiene
          │    Urine     │  Water     │   Hygiene    │  Water   →
          │  Processor   │  →         │    Water     │
          │              │            │  Processor   │
          └──────┬───────┘            └──────────────┘
                 │
                 ↓
               Brine
```
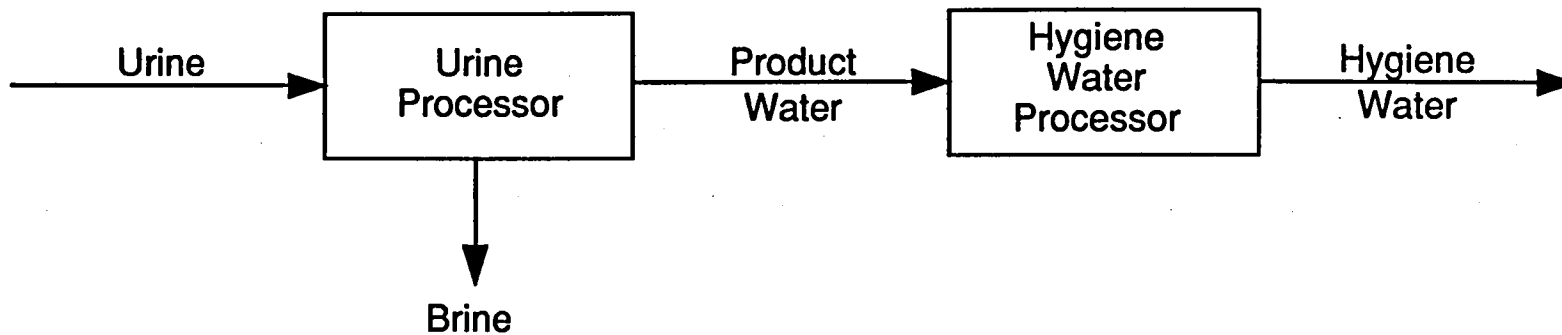
POTABLE WATER RECOVERY

THIS CHART PRESENTS THE FUNCTIONAL DESCRIPTION OF THE POTABLE WATER PROCESSOR SUBSYSTEM

FOR THE SPACE STATION FREEDOM PROGRAM. PROVIDED ALSO IS A GENERAL SCHEMATIC DISPLAYING

THE PRIMARY INPUTS AND OUTPUTS OF THE UNIT.

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Potable Water Recovery

Functional Description:

- Recover Water From Humidity Condensate And CO_2 Reduction Product Water
- Supply Potable Water For Crew (6.26-11.35 LBM/PERSON-DAY)
- Water Quality Must Meet PDRD Specifications
- Supply Water To All Modules At Specific Use Points

Humidity
Condensate

H_2O ⟶

CO_2 ⟶
Reduction H_2O

Potable
Water
Processor

Potable
H_2O ⟶
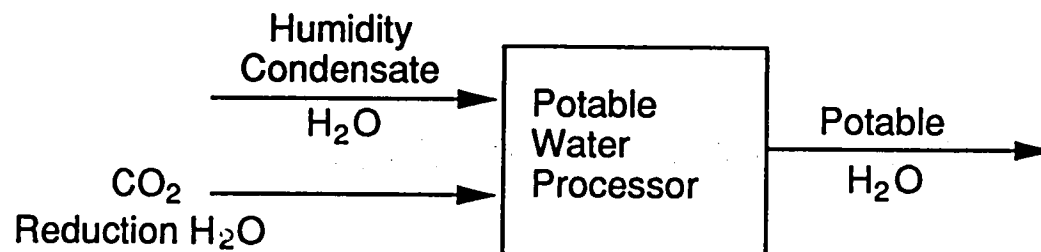
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Environmental Control and Life Support System

Invited Presentations

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– A Workshop

NASA

Environmental Control and Life Support System
Evolution

Paul Wieland
Life Support Branch/ED62

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
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Environmental Control And Life Support System Evolution

I. Introduction: Space Station *Freedom* Evolution Impact on the ECLSS

The Space Station *Freedom* Environmental Control and Life Support System (ECLSS) will have to accommodate the changes to *Freedom* as it evolves over the design life of 30 years or more. Requirements will change as pressurized modules are added, crew numbers increase, and as the tasks to be performed change. This evolution will result in different demands on the ECLSS and the ECLSS will have to adapt. Technologies other than the baselined ones may be better able to perform the various tasks and technological advances will result in improved life support hardware having better performance, increased reliability, reduced power consumption, weight, and volume, greater autonomy, and fewer resupply requirements. A preliminary study was performed to look at alternative technologies for life support and evaluate them for their integration requirements, focusing on the fluid line interface requirements. (A follow-on study will expand greatly on the scope of this preliminary study.) The integration requirements of the alternative technologies may be different from those of the baselined technologies. If this is the case, then by designing the initial space station to have the necessary fluid lines, etc. required by the selected alternative technologies then the task of replacing the baselined ones will be greatly simplified, thereby reducing the cost in on-orbit time as well as dollars.

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345

Space Station *Freedom* Evolution Impact on the ECLSS

○ Space Station *Freedom* will evolve over its 30 year or more lifetime, as pressurized modules are added, crew numbers increase, and as the tasks to be performed change.

○ Requirements placed on the ECLSS will also change.

○ During this time technological advances will lead to improved life support hardware which is better able to meet the new requirements.

○ Replacing the initial hardware with the improved technologies will be simplified if the integration requirements of the improved technologies are built into the initial *Freedom* design.

○ To better understand the integration requirements a preliminary study was performed to identify the fluid line interface requirements of the advanced technologies most likely to replace the initial technologies.

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346

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Advanced ECLSS Technology:
Benefits and Integration Requirements

O Benefits of Advanced ECLSS Technologies:
- Better performance
- Increased reliability
- Reduced power consumption, weight, and volume
- Greater autonomy
- Fewer resupply requirements

O Integration Requirements of Advanced ECLSS Technologies:
- System–level integration needs
- Fluid interface requirements
- Electrical power requirements
- Thermal control requirements
- Control/data requirements
- Resupply needs

347

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II. Objectives of the Study

The objectives of the preliminary study were to provide answers to some basic questions:
    (1) What requirements will be placed on the ECLSS in the future?
    (2) How will these requirements differ from the initial *Freedom* ECLSS requirements?
    (3) What constraints will affect the ECLSS?
    (4) What technologies will be available to meet the future ECLSS requirements?
    (5) What are the integration requirements of the alternative technologies?
    (6) How do these integration requirements differ from those of the baselined ECLSS subsystems?
    (7) What "scars" would facilitate transparent incorporation of the alternative technologies?

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– A Workshop

NASA

Objectives of the Study

The objectives of the preliminary study were to answer some basic questions:

(1) What requirements will be placed on the ECLSS in the future?

(2) How will these requirements differ from the initial *Freedom* ECLSS requirements?

(3) What constraints will affect the ECLSS?

(4) What technologies will be available to meet the future ECLSS requirements?

(5) What are the integration requirements of the alternative technologies?

(6) How do these integration requirements differ from those of the baselined ECLSS subsystems?

(7) What "scars" would facilitate transparent incorporation of the alternative technologies?

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NASA

III.   Approach Used

A two-part approach was used to identify the requirements placed on the future ECLSS and to identify and evaluate alternative technologies for their abilities to meet those needs.

A. Identification of Future ECLSS Requirements

The NASA documents which define the initial space station design and possible growth scenarios were reviewed for identification of the ECLSS requirements. These documents include: Space Station Program Definition and Requirements Document (PDRD) SSP 30000, Sec. 3; Space Station Mission Requirements Data Base (MRDB); the Space Station Systems Requirements Document, SS-SRD-0001, Sec. 3; MSFC Logistics System Evolution Study; and Growth Requirements for Multidiscipline Research and Development on the Evolutionary Space Station, NASA TM 101497.

From these documents groundrules and assumptions were derived and scenarios which are representative of the most likely evolution paths were identified. It was then possible to identify ECLSS associated constraints.

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Technology For Space Station Evolution
– A Workshop

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Two–Part Approach

O Identify Future ECLSS Requirements

● Review of NASA documents defining the space station design and growth scenarios

● Derive groundrules and assumptions affecting the ECLSS

● Identify scenarios representative of the most likely evolution paths

● Identify constraints associated with the ECLSS

O Identify and Evaluate Alternative Technologies

● Define the ECLSS functions to be considered

● Identify alternative technologies to perform those functions

● Evaluate the integration requirements of the alternative technologies

● Determine the "scars" needed to allow for easy replacement of the baseline technologies

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1. Groundrules and Assumptions

The groundrules and assumptions used as a basis for the study are:

(1) The ECLSS will provide the capability to depressurize and repressurize all airlocks and hyperbaric airlocks, and will be responsible for makeup of gases lost during airlock operations.

(2) The ECLSS will be responsible for the supply of Extravehicular Mobility Unit (EMU) potable water, oxygen, and air, and for processing of the EMU CO_2, urine, and condensate water.

(3) The ECLSS will be responsible for animal habitat requirements [but the Process Materials Management System (PMMS) will be responsible for experiment (ultrapure) water].

(4) The ECLSS will be responsible for animal laboratory requirements [but the Fluid Management System (FMS) will be responsible for experiment makeup water].

(5) The ECLSS will grow by module, i.e., all full sized Lab and Hab modules will contain the same ECLSS equipment as the baseline.

(6) All pressurized elements (modules, resource nodes, airlocks, pocket labs, etc.) will contain Temperature and Humidity Control (THC) subsystems.

(7) Intermodule ventilation will use a series/parallel scheme, with the resource nodes serving as plenums for supplying air to the attached pressurized elements.

(8) EMU-type ECLSS support will be provided to all manned transfer vehicles.

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353

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2. Representative Evolution Scenarios and ECLSS Associated Constraints

Two evolution scenarios, the Multi–Discipline Research Scenario and the Transportation Node Scenario, were used as a basis for defining the requirements that will be placed on the ECLSS in the future. Constraints affecting the ECLSS could then also be identified.

a. Multi–Discipline Research Scenario

The Multi–Discipline Research Scenario provides: "pressurized volume, payload attach points, crew time, electrical power and other essential resources to a diverse user community in support of their scientific research, technology development and commercial endeavors in space." (NASA TM 101497)

For this scenario the number of connected pressurized modules could increase to as many as 6 Lab modules and 3 Hab modules, with the necessary nodes to connect them and up to 3 pocket labs in addition. The crew size could increase to as many as 24 or more, to operate the experiments and operate and maintain *Freedom*.

It is expected that some experiments may require large amounts of EVA time occasionally, for example, during setup or servicing.

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Multi-Discipline Research Scenario

○ The Multi-Discipline Research Scenario provides: "pressurized volume, payload attach points, crew time, electrical power and other essential resources to a diverse user community in support of their scientific research, technology development and commercial endeavors in space." (NASA TM 101497)

○ Features Affecting the ECLSS:
- Up to 6 Lab modules, 3 Hab modules, nodes, and 3 pocket labs
- Crew size: 24 or more
- Large amounts of EVA time occasionally (during experiment setup or servicing)

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b. Transportation Node Scenario

The Transportation Node Scenario is less well defined at this time. For this scenario *Freedom* serves as a waypoint for missions beyond Low Earth Orbit (LEO). Tasks to be performed include servicing of transfer vehicles, assembly of large spacecraft, and processing of returned payloads.

Large amounts of EVA time on a regular basis are associated with using *Freedom* as a transportation node. Using the present airlock design, a two–person EVA transfer would involve up to 10% air loss by volume per cycle. For servicing of the Lunar Transfer Vehicle (LTV), which would require up to 40 hours per day, about 10 pounds of resupply air per day are required.

One scenario for the transportation node includes an isolated Hab module remote from the main cluster, with two nodes and an airlock, for use by four crew members dedicated to vehicle buildup and servicing tasks.

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Transportation Node Scenario

◯ The Transportation Node Scenario is less well defined at this time. For this scenario *Freedom* would serve as a waypoint for missions beyond low Earth orbit. Tasks to be performed include servicing of transfer vehicles, assembly of large spacecraft, and processing of returned vehicles and payloads.

◯ Features Affecting the ECLSS:
   ● Large amounts of EVA time on a regular basis (up to 40 hours per day for servicing of the Lunar Transfer Vehicle)
   ● Increased resupply of lost air and water

357

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c. ECLSS Associated Constraints

There are various constraints associated with different growth scenarios. Critical factors which affect the ECLSS include available power, crew time for maintenance, and launch mass (for resupply needs). Safe haven considerations require that, in an emergency, a single ECLS subsystem group be capable of supporting eight people. Module growth patterns may be limited by the IMV system. Increases in crew size and the number of modules are to maintain a 4:1 crew to US module ratio or an 8:1 crew to US Hab module ratio.

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Constraints Affecting the ECLSS

○ Critical factors affecting the ECLSS include:
- Available power
- Crew time for maintenance
- Launch mass for resupply

○ Safe haven requirements

○ Module growth
- Growth patterns may be limited by the Intermodule Ventilation system
- A ratio of 4:1 crew members to number of U. S. modules, or 8:1 crew to U. S. Hab modules, is to be maintained

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B. Identification and Evaluation of Alternative Technologies

Alternative technologies for each ECLSS task were identified and those that could be developed to perform the ECLSS tasks were evaluated for their integration needs. The fluid line interface needs were then compared with those of the baseline ECLSS and the "scars" required to permit replacement subsystems with alternative subsystems were identified.

1. ECLSS Functions Considered

The ECLSS consists of several tasks, each consisting of one or more functions: Air Revitalization, Water Recovery and Management, Atmosphere Control and Supply, Temperature and Humidity Control, Fire Detection and Suppression, and Waste Management. The ECLSS functions considered in this study are: CO_2 removal, CO_2 reduction, O_2 generation, trace contaminant control, urine recovery, potable water recovery, hygiene water recovery, and waste management.

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ECLSS

Atmosphere Revitalization (AR)

- CO_2 Removal
- CO_2 Reduction
- O_2 Generation
- Contaminant Control and
Monitoring

Atmosphere Control and Supply (ACS)

- O_2/N_2 Storage and Distribution
- Vent and Relief
- O_2/N_2 Pressure Control

Water Recovery and Management (WRM)

- Urine Processing
- Hygiene Water Processing
- Potable Water Processing
- Water Storage and Distribution
- Water Thermal Conditioning
- Water Quality Monitoring

Temperature and Humidity Control (THC)

- Air Temperature Control
- Humidity Control
- Ventilation
- Equipment Air Cooling
- Thermally Conditioned Storage
- Refrigerator/Freezer

Fire Detection and Suppression (FDS)

Waste Management (WM)

- Return Waste Storage
- Fecal Processing and Management

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2. Identification of Alternative Technologies

Alternative technologies for the ECLSS tasks were identified by reviewing technical papers and reports (NASA and other) and through contacts with scientists and engineers working on ECLSS technology development.

3. Evaluation of the Integration Needs of Each Technology

After identifying the alternative technologies and developing a basic understanding of how each works or would work the next step was identification of the integration requirements, focusing on the fluid interface requirements.

4. Determination of the "Scars" Required for Each Technology

The fluid interface requirements of the new technologies were then compared with those of the baseline technologies and the ones not needed by the baseline technologies were identified. These then determine the required "scars."

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Identification and Evaluation of Alternative Technologies

◯ Identification of Alternative Technologies
  ● Literature search: review of technical papers and reports
  ● Contacts with scientists and engineers working on ECLSS technology development

◯ Evaluation of the Integration Needs
  ● Basic understanding of the alternative technologies
  ● Identify the integration needs of each, focusing on the fluid interface requirements

◯ Determination of the Fluid Interface "Scars" Required
  ● Compare the interfaces of the alternative and baseline technologies
  ● The interfaces not required by the baseline technologies then determine what "scars" will be required

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IV. Results

A. Database of the Alternative Technologies

A database was created, and computerized, with descriptions, of the alternative technologies and the references where the information was obtained. This database will be expanded as more information becomes available.

B. Types of "Scars" Identified

The "scar" requirements for the alternative technologies fall into three general levels: (1) intrarack, (2) interrack (rack interface plate), and (3) module or cluster level. It is assumed that replacement of the ECLSS hardware would occur at the rack level, therefore "scars" at the intrarack level can be ignored. At the interrack or rack interface plate level there may be a need to add extra fluid lines (for example, to provide cooling water not originally needed) or to oversize the tubing or ducting to accommodate a higher flow rate than initially required. On the module or cluster level, additional ECLSS resupply tanks or an additional tank farm (with associated valves, pressure regulators, instrumentation, etc.) may be needed in order to meet the requirements of high levels of EVA and airlock usage.

C. Issues and Areas for Further Study

The results of the preliminary study identified several issues and areas to be studied further. More definitive data is needed on the Transportation Node Scenario to adequately determine the requirements and constraints on the ECLSS. Additional Intermodule Ventilation (IMV) analyses are needed in order to evaluate the effects of adding modules in various configurations. The effects of various crew distributions on the pCO_2 and pO_2 levels is also needed. Safe haven requirements may change as *Freedom* evolves and this needs to be evaluated further.

D. Scope of the Follow-on Study

The follow-on study will greatly expand the scope of the preliminary study in several ways:
(1) Computer models of the alternative technologies will be developed and incorporated into existing analysis tools,
(2) A prioritized list of the potential technologies will be developed and a more thorough assessment of the software control "hooks" and hardware "scars" performed,
(3) A comparative analysis will be performed against the baseline system, and
(4) Cost/benefit trade studies will be performed to identify the best candidates to replace the baseline technologies.

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Results

○ Database of Alternative Technologies

○ Three Levels of "Scars" Identified
  ● Intrarack
  ● Interrack
  ● Module or cluster

○ Issues and Areas for Further Study
  ● More definition of the Transportation Node Scenario is needed
  ● Additional analyses of Intermodule Ventilation are needed to evaluate the effects of adding modules in various patterns
  ● Additional analysis of the effects of crew distribution is needed
  ● Possible changes to Safe Haven requirements as *Freedom* evolves need to be evaluated

○ Expanded Scope of the Follow-on Study
  ● Computer models of the alternative technologies will be developed and incorporated into existing analysis tools,
  ● A prioritized list of the potential technologies will be developed and a more thorough assessment of the software control "hooks" and hardware "scars" performed,
  ● A comparative analysis will be performed against the baseline system, and
  ● Cost/benefit trade studies will be performed to identify the best candidates to replace the baseline technologies.

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Technology for Space Station Evolution Workshop
Dallas, Texas - January 16-19, 1990

Title:

TECHNOLOGIES FOR ECLSS EVOLUTION

Presenter:

Bryce L. Diamant
McDonnell Douglas Space Systems Company
Huntsville, Alabama

Performed under contract NAS8-36407 for NASA MSFC

TECHNOLOGY FOR SPACE STATION EVOLUTION WORKSHOP
Dallas, Texas - January 16-19, 1990

Presentation Title

TECHNOLOGIES FOR ECLSS EVOLUTION

Presenter

Bryce L. Diamant - Engineer
McDonnell Douglas Space Systems Company
Huntsville, Alabama
(205) 721-7274

Introduction

In this presentation characteristics of existing and advanced physio-chemical technologies are discussed for the Atmosphere Revitalization (AR), Water Recovery and Management (WRM), and Waste Management (WM) subsystems of the Space Station Freedom Environmental Control and Life Support System (ECLSS). All technologies discussed have undergone some degree of experimental testing, and many competed for the space station ECLSS baseline. The primary qualitative advantages and disadvantages of each technology are summarized. Technologies are discussed for the following systems: CO_2 removal, CO_2 reduction, O_2 generation, trace contaminant control, urine processing, hygiene water processing, potable water processing, and waste processing.

OVERVIEW

Introduction:

Existing and advanced physio-chemical technologies are discussed for the Atmosphere Revitalization (AR), Water Recovery and Management (WRM), and Waste Management (WM) subsystems of the space station ECLSS.

Main Body:

Discuss operation, advantages, disadvantages of following:

I. Atmosphere Revitalization (AR)

CO_2 Removal
CO_2 Reduction
O_2 Generation
Trace Contaminant Control

II. Water Recovery and Management (WRM)

Urine Processing
Hygiene Water Processing
Potable Water Processing

III. Waste Management (WM)

Summary:

List of technologies.

CO2 Removal

Baseline Technology

Four-Bed Molecular Sieve (4BMS)
The 4BMS is composed of two adsorbing sorbent beds, one a desiccant bed for water vapor removal, the other a Zeolite 5A molecular sieve for trapping CO_2. This bed pair operates in parallel with an identical pair of beds in the desorbing mode. Adsorption of CO_2 from the process air is accomplished at low temperature. The adsorbing bed is then heated to desorb the CO_2 to a reduction device. The 4BMS is a mature, flight-proven technology. A similar system was flown on Skylab, where CO_2 was desorbed to space. The 4BMS has no significant impacts on other space station systems, although its power requirement and volume are higher than other available technologies.

Candidate Substitute Technologies

Solid Amine Water Desorbed (SAWD)
The SAWD operates similarly to the 4BMS, although no desiccant beds are required. The SAWD uses steam-heated solid amine (WA-21) beds to adsorb CO_2. Desorption is accomplished by steam-heating the CO_2-laden beds. Solid amines degrade more rapidly than Zeolites, decreasing bed efficiency and increasing bed changeout frequency and resupply. SAWD also penalizes the ECLSS by requiring hygiene water, which is eventually vented in vapor form to the Temperature and Humidity Control System (THC), increasing the load on the cabin condensing heat exchanger. Since condensate is used for potable water, the loss of hygiene water due to the SAWD appears as a gain in the potable supply. SAWD has the advantage that desorption takes place at cabin pressure rather than at the near vacuum conditions required by the 4BMS.

Electrochemical Depolarized CO2 Concentrator (EDC w/H2)
The EDC reacts H_2 and O_2 inside an electrochemical cell with cabin air containing CO_2, producing two output streams. The reaction is :
$$2CO_2 + 2H_2 + O_2 \longrightarrow 2H_2O + 2CO_2 + \text{electric power.}$$
The output from the anode-side cavity of the cell has a high concentration of CO_2 and some H_2, while the cathode-side cavity output contains air with a low CO_2 concentration that is returned to the cabin. The EDC eliminates inefficient cycling required by technologies that must repeatedly heat and cool adsorbing/desorbing beds. EDC has the disadvantages of consuming oxygen and producing water vapor, increasing the respective loads on the oxygen generation and humidity control systems. EDC is also a safety hazard due to the potential for hydrogen leakage into the cabin atmosphere, which could lead to a fire or explosion. No other CO_2 removal technology employs H_2 in the removal process.
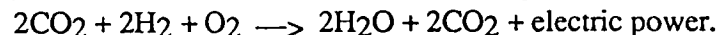
AR - CO2 REMOVAL

Baseline Technology

Four-Bed Molecular Sieve (4BMS)
+ Mature flight-proven technology.
+ Low system impacts.
- High power and volume.

Candidate Substitute Technologies

Solid Amine Water Desorbed (SAWD)
+ Only two sorbent beds required, reducing complexity relative to the 4BMS.
+ Ambient pressure desorption. Vacuum pressures not required.
- Impacts to Temperature and Humidity Control system and hygiene water supply.
- Degradation of solid amine beds reduces efficiency and increases resupply.

Electrochemical Depolarized Concentrator (EDC w/H2)
+ Eliminates inefficient cycling.
- Potential for hydrogen leakage is safety concern.
- System impacts on O2 Generation and Temperature and Humidity Control systems.

CO$_2$ Removal

Air Polarized CO$_2$ Concentrator (APC or EDC w,wo/H$_2$)
This technology is simply an EDC not requiring H$_2$ for the CO$_2$ removal process. The capability to operate without hydrogen reduces the safety concern, although the APC will likely alternate between operating with and without hydrogen to minimize system power requirements. However, switching between operating with and without H$_2$ accelerates degradation of the cell electrode catalyst. The APC requires an O$_2$/CO$_2$ separator, slightly increasing its weight, power, volume, and complexity relative the EDC.

Two-Bed Molecular Sieve (2BMS)
The 2BMS is similar to the 4BMS, although the 2BMS utilizes a carbon molecular sieve (CMS) instead of Zeolite to adsorb CO$_2$. CMS material preferentially adsorbs CO$_2$ over water vapor, eliminating the need for the two desiccant beds found in the 4BMS. This reduces system power, weight, volume, and complexity relative to the 4BMS without any additional system impacts. CMS material also desorbs at a lower temperature than Zeolite, further decreasing power requirements. The 2BMS is still under development.

Membranes
The use of membrane technology to effectively concentrate CO$_2$ would likely result in a simple, light, small, low power CO$_2$ removal system. However, the gas selectivity of current membrane technology is inadequate. Instead of filtering all other gases besides CO$_2$ from the process air to produce a stream of high CO$_2$ concentration, the membranes also filter out some CO$_2$ and return it to the cabin. This inefficient process requires large membranes to remove relatively small quantities of CO$_2$.

AR - CO2 REMOVAL

Air Polarized CO2 Concentrator (APC or EDC w,wo/H2)

+ Safety concern reduced.
- W/Wo H_2 operation reduces power consumption, but accelerates electrode catalyst degradation.
- O_2/CO_2 separator decreases power, weight, volume relative to EDC w/H_2.
• Advanced version of EDC still under development.

Two-Bed Molecular Sieve (2BMS)

+ Elimination of desiccant beds reduces system power, weight, volume, complexity.
+ Carbon molecular sieve desorbs at lower temperature than Zeolite, reducing power usage.
• System still under development.

Membranes

+ Potential for low weight, power, volume, complexity.
- Highly inefficient due to poor gas selectivity.

CO$_2$ Removal

Fluid Interfaces

The space station must be designed to easily incorporate advanced technologies that could forseeably replace the baseline technologies in the future. Designing the station for easy on-orbit technology replacement is referred to as scarring the station. Scarring ensures that all interfaces required by an advanced technology will be available when it comes time to replace the old technology. These interfaces include any fluid interfaces, such as a line to the liquid coolant loop, a gas vent line to trace contaminant control, or a CO$_2$ output line to the Bosch. Fluid interfaces for advanced technologies not required by the baseline technology are plumbed from the module standoffs to the rack(s) expected to house the future technologies and capped off. These temporarily unused fluid lines are station scars. The included table is a list of the fluids input to and output from CO$_2$ technologies. These fluid interfaces were obtained by studying available schematics for each technology. Similar tables for the other subsystems (urine processing, trace contaminant control, etc.) are included in this packet, but are not presented.

CO$_2$ REMOVAL

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Four-Bed Molecular Sieve	Cabin Air Liquid Coolant	Return Air CO$_2$, Liquid Coolant
Two-Bed Molecular Sieve	Cabin Air Liquid Coolant	Return Air CO$_2$, Liquid Coolant
EDC	Cabin Air, N$_2$ Purge Liquid Coolant, H$_2$	Return Air, H$_2$/CO$_2$, Liquid Coolant
SAWD	Cabin Air Hygiene Water	Return Air Steam Pressure Vent, CO$_2$
APC	Cabin Air Liquid Coolant H$_2$, N$_2$ Purge	Return Air, H$_2$/CO$_2$ Liquid Coolant
Membranes	Cabin Air	Return Air CO$_2$

CO2 Reduction

Baseline Technology

Bosch Reactor

Carbon dioxide is reacted with hydrogen at high temperature (1050°F) in the presence of a nickel catalyst, producing solid waste carbon and water for the potable supply. The reaction is:

$$CO_2 + 2H_2 \longrightarrow C + 2H_2O.$$
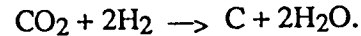
A single pass through the Bosch reactor reduces only about 11% of the input CO_2, with efficiency decreasing as carbon builds up in the collection cartridges. Complete, 100% conversion is achieved by continuously recirculating the process gases. Bosch carbon cartridges must be resupplied; however, the issue of carbon cartridge replacement vs. replacement of the entire core reactor is still undecided.

Candidate Substitute Technologies

Sabatier Reactor

Carbon dioxide is reacted with hydrogen at high temperature in the presence of a ruthenium catalyst on a granular substrate, producing methane and water. The reaction is:

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O.$$
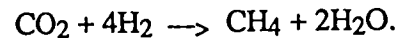
Sabatier has the advantage of being smaller and requiring much less power than Bosch; however, the toxic methane it produces must by vented to space or stored at a high weight and volume penalty. Both of these methods are currently impractical. Sabatier would be a very attractive technology if its product methane could be used as a propellant for space station attitude control resistojets. The Sabatier reactor has a conversion efficiency greater than 98%; however, anything less than 100% results in the loss of oxygen molecules in the form of unreacted CO_2. Loss of O_2 combined with loss of H_2 in the product CH_4 is a costly disadvantage of Sabatier. The water and oxygen supplies will be slowly depleted, ultimately necessitating increased resupply.

Advanced Carbon Reactor (ACR)

The ACR consists of a Sabatier reactor, a gas/liquid separator to remove product water from methane, and a carbon formation reactor (CFR) to reduce methane to carbon and hydrogen. The reaction inside the carbon formation reactor is:

$$CH_4 \longrightarrow C + 2H_2$$
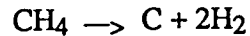
The ACR carbon collection cartridges pack carbon more neatly than the Bosch, reducing resupply. A disadvantage of the ACR is that both the catalytic and pyrolytic versions of the CFR operate above 1600°F, which may present materials problems. The ACR is still under development.

CO2 Electrolysis

See the section on O_2 Generation. CO_2 electrolysis is a dual-function technology, where CO_2 is reduced to produce oxygen. CO_2 electrolysis does not require hydrogen as a reactant for the reduction process, although it therefore produces no water for the potable supply. Some hydrogen will appear in the output stream due to electrolysis of water vapor.

AR - CO2 REDUCTION

Baseline Technology

Bosch Reactor
+ 100% CO_2 conversion.
- Single pass CO_2 conversion efficiency only 11%.
- Carbon collection device must be resupplied.

Candidate Substitute Technologies

Sabatier Reactor
+ Potential for lowest weight, power, volume.
- Incomplete CO_2 conversion necessitates water resupply.
- High weight and volume penalty for waste gas storage.

Advanced Carbon Reactor (ACR)
+ High density carbon packing reduces resupply.
- High temperature operation may present materials problems.
• Technology still under development.

CO2 Electrolysis
+ Dual function technology.
+ Electrolysis of water vapor reduces humidity.
+ H_2 not required as a reactant.
- Water not produced for the potable supply.
- Potential for carbon monoxide leakage.
- High operating temperatures present materials problems.
- Requires Boudouard reactor.
• New technology still under development.
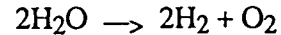
O2 Generation

Baseline Technology

Static Feed Water Electrolysis (SFWE)

The SFWE electrolyzes hygiene water to produce oxygen. The reaction is:

$$2H_2O \longrightarrow 2H_2 + O_2$$

Water resting statically in a feed compartment diffuses as a vapor through the water feed membrane and into an aqueous KOH electrolyte. This passive water feed mechanism has the advantage of no moving parts. Oxygen gas is produced at the anode of the electrolysis cell, while hydrogen is produced at the cathode. Product hydrogen is sent to the CO_2 reduction system. The SFWE is a mature technology that has been tested extensively.

Candidate Substitute Technologies

Liquid Anode Feed Solid Polymer Electrolysis (SPE)

Similar in concept to the SFWE, the SPE electrolyzes water using a solid polymer electrolyte (sulfonated perfluoro-linear polymer). SPE requires that feed water be in direct contact with the cell anode to provide cooling during the electrolysis process. The need for two liquid/gas separators and a deionizer bed increases SPE system complexity relative to the SFWE. The deionizer is needed to remove contaminants from the hygiene feed water that could otherwise corrode the anode. SPE cell stack technology has been tested extensively, and has been used successfully in submarines.

CO2 Electrolysis

CO_2 electrolysis is a dual-function technology, simultaneously performing carbon dioxide reduction and oxygen generation. By combining two functions into one technology, total AR system weight, power, volume, and complexity may be reduced. CO_2 is electrolyzed using a solid oxide electrolyzer, producing O_2 and CO. The electrolysis cell reaction is:

$$CO_2 + H_2O \longrightarrow CO + O_2 + H_2$$
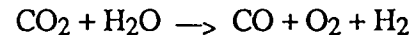
CO is then catalytically decomposed in a Boudouard reactor into solid carbon and CO_2, and this CO_2 is recycled to the electrolysis unit. Water vapor in the process stream is also electrolyzed, which helps control cabin humidity. CO_2 electrolysis places no burden on the hygiene water supply, virtually eliminating two-phase (liquid/gas) processing, although it penalizes the potable water supply by being the only technology performing CO_2 reduction that does not produce potable water. CO_2 electrolysis operates at very high temperatures (above 1600°F), presenting materials problems, and may have the potential for dangerous carbon monoxide leakage. The CO_2 electrolyzer and particularly its associated Boudouard reactor are new technologies requiring further development.

Water Vapor Electrolysis (WVE)

WVE electrolyzes water vapor directly from cabin air, producing oxygen and hydrogen. Cabin air containing moisture is fed to the anode-side compartment of the SFWE-style electrolysis cell, producing an O_2-enriched stream at the anode and hydrogen at the cathode. WVE helps control cabin humidity and, having few interfaces, lends itself as a portable technology to augment the central O_2 generation system for situations when additional oxygen is needed, such as when the crew gathers for a significant period of time.

AR - O2 GENERATION

Baseline Technology

Static Feed Water Electrolysis (SFWE)
+ Extensively tested, mature technology.
+ Passive water feed mechanism has no moving parts.

Candidate Substitute Technologies

Liquid Anode Feed Solid Polymer Electrolysis (SPE)
+ Extensively tested, mature cell stack technology.
- Two liquid/gas separators and a deionizer increase system complexity.

CO_2 Electrolysis
+ Dual function technology.
+ No penalty to the hygiene water supply.
+ Eliminates two-phase (liquid/gas) processing.
+ Electrolysis of water vapor reduces cabin humidity.
- Potential for carbon monoxide leakage.
- High operating temperatures present materials problems.
- Requires Boudouard reactor.
• New technology requiring further development.

Water Vapor Electrolysis (WVE)
+ Helps control cabin humidity.
• Potential as a portable technology to augment centralized system.

Trace Contaminant Control

Baseline Technology

Carbon Adsorption Beds with Catalytic Oxidizer

Charcoal (carbon) adsorption beds coupled with platinum catalytic oxidizers remove trace contaminants, such as freons and aromatics, from cabin air. The charcoal beds, similar to those found on previous manned space flight missions, are expendable, incurring a large resupply penalty. This costly disadvantage may eventually be eliminated by developing a safe regenerable system. Pre and post sorbents are required for the oxidizer to prevent catalyst poisoning by halogenated hydrocarbons and acidic gases, such as sulfur oxides. These additional sorbents increase system complexity.

Candidate Substitute Technologies

Reactive Bed Plasma (RBP)

RBP decomposes contaminants at low temperature (250°F) using a synergistic combination of plasma and catalyst. Process air passes through an annular reactor filled with alumina catalyst, where it is electrically ionized into plasma. The main function of the catalyst is to increase the time contaminant molecules spend in the active plasma region, where plasma-generated high energy electrons and subsequently produced species (mainly active oxygen) oxidize toxic materials. In addition, RBP can perform as a highly efficient electrostatic precipitator to collect and deactivate hazardous particulate material. The RBP system includes low temperature (150°F) regenerable post-treatment of toxic reaction products, particularly nitrous oxides. RBP completely reduces methane, and the system is very difficult to poison. The RBP system currently has a high power requirement of about 1000 W. Another disadvantage is that RBP performance may be degraded by electromagnetic interference, although the magnitude of this problem is presently unclear. RBP is currently under development.

AR - TRACE CONTAMINANT CONTROL

Baseline Technology

Carbon Adsorption Beds with Catalytic Oxidizer
+ Highly mature technology.
- Expendable charcoal beds incur a large resupply penalty.
- Pre/post sorbents for oxidizer are required to avoid catalyst poisoning.

Candidate Substitute Technologies

Reactive Bed Plasma (RBP)
+ Acts as a highly efficient electrostatic precipitator.
+ Low temperature (250°F) operation.
+ Complete methane reduction.
+ Extremely difficult to poison.
- High power requirement.
- Conversion of CO to CO_2 burdens the CO_2 reduction system.
- Performance may be degraded by electromagnetic interference.
• New system currently under development.

381

Urine Processing

Baseline Technology

Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)
Before entering the TIMES unit, process urine/flush water is pretreated with oxone and sulfuric acid to fix free ammonia, inhibit microbial growth, control odor, and reduce foaming. The pretreated urine/flush water enters the TIMES through two parallel heat exchangers in contact with the hot side of a thermoelectric heat pump. The heated waste water then flows through hollow fiber membranes that make up the evaporator section of the subsystem, consisting of 600 Nafion tubes assembled into six bundles of 100 tubes each. Long term reliability of the joints connecting the Nafion tubes to the bundle headers is currently a TIMES concern. Water diffuses through the membranes and evaporates from their outer surfaces, which are maintained at low pressure. This steam flows to the main condenser, which is in contact with the cold side of the thermoelectric heat pump. Partially condensed, the steam then flows to an air-cooled heat exchanger, where the condensation process is completed. Latent heat is recovered and reused in the evaporative process. The condensate is tested for water quality and, if acceptable, is delivered as product water to the hygiene processor by a centrifuge-type pump. The pump acts as a gas/liquid separator since it removes non-condensible gases entrained in the condensate stream. Unacceptable condensate is reprocessed. With water recovery efficiency less than 100% (90-95%), the TIMES process involves brine storage, which is a weight, volume, and resupply penalty.

Candidate Substitute Technologies

Vapor Compression Distillation (VCD)
VCD maintains a vapor/liquid interface using centrifugal force created by a rotating drum. This is more complicated than the static phase separation process employed by the TIMES. Water is evaporated from a thin film of process waste water flowing over the inner surface of a rotating evaporator/condenser drum. The water vapor is compressed, raising its saturation temperature, then directed out of the drum and against its outside surface, where it condenses. The latent heat of condensation is transferred passively from the outside to the inside of the drum through its thin metallic wall, providing the latent heat required to evaporate the next batch of incoming waste water. This passive latent heat transfer makes VCD an energy efficient process. After startup, the only energy used by the process is for water vapor compression and for overcoming mechanical and thermal inefficiencies. Unevaporated waste water is recirculated until the solids concentration builds up to a predetermined level, at which time the concentrated brine is removed for storage. The VCD brine storage penalty is nearly identical to that of the TIMES. A disadvantage of VCD is that its rotating/vibrating parts may create forces that could disrupt the space station microgravity environment. Additionally, mechanical reliability of the peristaltic feed pump is still in question.

WRM - URINE PROCESSING

Baseline Technology

Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)
+ Waste water phase separation is a static process.
- Membrane mechanical reliability questionable over long term.
- Less than 100% water recovery necessitates brine storage.

Candidate Substitute Technologies

Vapor Compression Distillation (VCD)
+ Produces slightly higher water quality and processes higher flow rates than TIMES.
+ Lowest power consumption due in part to passive latent heat recovery.
- Dynamic waste water phase separation more complex than TIMES static separation.
- Less than 100% water recovery necessitates brine storage.
- Mechanical reliability of peristaltic feed pump questionable.

Urine Processing

Air Evaporation System (AES)

In the AES, pretreated urine is pumped through a particulate filter to a wick package using a pulse feed technique. The pulse and urine flow rate are controlled by a feed pump that responds to the relative humidity of air leaving the wick package and the amount of liquid processed. Sufficient time is provided between pulses to allow the volume of urine to be distributed before the next pulse. A circulating heated air stream evaporates water from the urine, leaving urine solids in the wicks. When sufficient urine solids accumulate in the wicks, the feed pump is shut off and the loaded wicks are dried down and replaced with a new wick package. Storage of spent wick packages is likely to require less volume than brine storage. During dry-down, humid air leaving the wick package passes through a condensing heat exchanger. A water separator downstream of the condenser removes water from the air stream and pumps it to the product water loop. The complete dry-down procedure results in nearly 100% water recovery. Precise waste water feed control is critical to water recovery efficiency. Feeding too much waste water will saturate the sponge-like wicks, causing waste water to drip off the wicks and continue downstream before entrained contaminants can be absorbed. The complex feed control still requires further development. The AES was tested successfully in manned chamber tests by McDonnell Doulgas in the late 1960's, and involves a relatively simple, reliable process. The AES operates at ambient pressure, eliminating potential leakage problems and system impacts associated with vacuum pressures. AES is tolerant of solid precipitates, eliminating the need for an oxidizing pretreatment. Oxone urine pretreament is required by the TIMES to keep solid precipitates in solution during processing, but oxone is a corrosive, reactive chemical. Nonoxidizing pretreatments, which are safer and easier to handle than oxone, do not hold solid precipitates in solution. This is ideal for the AES, where solids must precipitate out into the wicks. The main disadvantage of AES is that it is an energy-intensive process, requiring much more power than its competitors. Methods for reducing energy consumption are being studied, all of which will likely increase system complexity.

Vapor Phase Catalytic Ammonia Removal (VPCAR)

VPCAR is based on a catalytic chemical process where impurities that vaporize with the process water are oxidized to innocuous gaseous products. The process employs two catalyst beds. In the first bed ammonia is oxidized to a mixture of nitrogen and nitrous oxide, and volatile hydrocarbons are oxidized to carbon dioxide and water vapor. In the second bed nitrous oxide formed in the first bed is catalytically decomposed into oxygen and nitrogen. VPCAR requires neither pretreatment nor posttreatment. As a first-generation system VPCAR produces higher quality water than its more mature competitors. Recovered water has little ammonia, few hydrocarbons, and low conductivity, requiring only adjustment of its pH to meet potable water standards. VPCAR employs the same potentially unreliable hollow fiber evaporator found in the TIMES, and has the additional disadvantage of operating at high temperatures of up to 850°F. VPCAR also requires brine storage, and the process impacts SFWE operation by consuming oxygen.

384

WRM - URINE PROCESSING

Air Evaporation System (AES)

+ Nearly 100% water recovery
+ Reliable, simple process.
+ Tolerant of solid precipitates. A nonoxidizing pretreatment becomes feasible.
+ Air evaporation loop operates at ambient pressure.
+ Storage of spent wick packages may require less volume than brine storage.
- Energy-intensive process.
- Complex control of wastewater feed to wicks requires further development.

Vapor Phase Catalytic Ammonia Removal (VPCAR)

+ First-generation system produces higher quality water than more mature competitors.
+ Pre/posttreatment not required.
- Consumes oxygen.
- Less than 100% water recovery necessitates brine storage.
- Operation at high temperature and pressure.
- More complex than other urine processors.
• New technology requiring further development.

Hygiene Water Processing

Baseline Technology

Reverse Osmosis (RO)

Non-phase change technologies, such as RO and MF, are chosen for hygiene water processing based on their low specific energy relative to phase change technologies and their ability to more readily process the high flow rates associated with hygiene water use. The RO system consists of an ultrafiltration (UF) unit and RO unit in series, each employing membranes for removing contaminants from waste water. Ultrafiltration is a process that filters most suspended solids and macromolecules, while allowing low molecular weight salts and water to permeate the membrane. As the first stage of the RO system, the primary function of UF is to remove large contaminants that would otherwise foul the RO membranes. In the RO unit a semipermeable membrane separates purified product water from input waste water. A pressure is applied to the waste water in excess of its osmotic pressure, reversing the normal osmosis process. Water spontaneously flows across the semipermeable membrane from the concentrated waste water solution to a less concentrated solution, resulting in product water with a reduced impurity concentration. The RO unit rejects all suspended solids, all macromolecules, and most low molecular weight salts, although current membranes are incapable of removing almost all groups of low molecular weight organics. Contaminant removal by membrane filtration is a more flexible method than removal by sorbent beds. Sorbent beds (employed by multifiltration) are designed to remove specific contaminants. An unexpected contaminant introduced into the hygiene water loop is more likely to be removed by the RO membranes than by the multifiltration sorbent beds. In addition, the unexpected contaminant may rapidly foul the sorbent beds. RO has the disadvantage of producing brine that must be processed by the urine processor. RO also requires posttreatment by multifiltration sorbent beds, which must be periodically changed out and resupplied.

Candidate Substitute Technologies

Multifiltration (MF)

See the section on potable water processing. MF system complexity is lower than RO, and it does not have the system impacts associated with brine handling (demand on urine processor and cycling of RO unit to allow for brine removal). MF has the disadvantage of being more sensitive to waste water characteristics than RO since its unibeds are designed to remove specific contaminants. MF is incapable of removing low molecular weight nonionic organics, particularly alcohols, ketones, and amides.

WRM - HYGIENE WATER PROCESSING

Baseline Technology

Reverse Osmosis (RO)
+ Filtration more flexible than contaminant removal by sorbents.
+ Low specific energy relative to phase change technologies.
+ Rejects all suspended solids, all macromolecules, and most low molecular weight salts.
- Incapable of removing almost all groups of low molecular weight organics.
- Requires brine processing by urine processor.
- Requires multifiltration posttreatment. Bed changeout is resupply, crew time penalty.

Candidate Substitute Technologies

Multifiltration (MF)
+ Low system complexity.
+ Low specific energy relative to phase change technologies.
+ Highest water recovery percentage.
+ Minimal system impacts.
- Incapable of removing low molecular weight, nonionic organics.
- Performance is sensitive to waste water characteristics.
- Bed changeout is high resupply, crew time penalty.

Potable Water Processing

Baseline Technology

Multifiltration (MF)

Potable water is obtained through multifiltration of condensate from the Temperature and Humidity Control (THC) subsystem and from water formed during the CO_2 reduction process. MF consists of a particulate filter upstream of six unibeds in series. Each unibed is composed of sorbent beds and ion exchange resin beds. After about 10-30 days the first unibed in the series will become contaminated. As the first bed to be exposed to input waste water, it becomes contaminated before the remaining unibeds downstream. Once its storage capacity is reached, this unibed is removed and the other five unibeds are moved up to fill the gap. A fresh unibed is placed at the end of the series. Unibed changeout is a resupply and crew time penalty, although the beds do not foul as quickly as the MF hygiene processor unibeds, which handle much dirtier waste water. Microbial growth is impeded by heating and chemically treating (iodine injected by a microbial check valve) the process water. MF has a higher water recovery percentage than RO.

Reverse Osmosis (RO)

See the section on hygiene water processing. RO/UF modules appear unnecessary for potable processing. Water quality entering the potable processor is relatively high. This water tends to pass through the RO/UF modules relatively unaffected, and the MF posttreatment unit winds up removing the majority of the entrained contaminants.

Electrodeionization

The electrodeionization process utilizes ion exchange resins and membranes to deionize contaminated feed water. Ion exchange membranes, used as barriers to bulk water flow, divide the system into three adjacent compartments - a diluting compartment bordered on either side by a concentrating compartment. Feed water enters the diluting compartment, which is filled with mixed-bed ion exchange resin. Ions in the feed solution react with the ion exchange resins, transferring through these resins in the direction of an electrical potential gradient applied across the compartments. Due to the semipermeability properties of the ion exchange membranes and the directionality of the potential gradient, ion concentration will decrease in the diluting compartment and increase in the concentrating compartments. The system outputs brine from the concentrating compartments and purified deionized water from the diluting compartment (conductivity as low as 0.1 microsiemen/cm). Pre- and posttreatment of the feed water is required to extract contaminants not removed by the electrodeionization process, including nonionic species, chlorine, and silica. Electrodeionization is capable of deionizing a wide range of feeds, from bulk salt removal to polishing of RO product water. In the electrodeionization system the ion exchange resin is continually electrically regenerated. Regeneration chemicals are not required, eliminating chemical handling, waste neutralization, and corrosion problems. Electrodeionization does not involve sorbent bed changeout required by MF and RO, although its pre/posttreatments will likely entail resupply and regular replacement of expendables by the crew. System disadvantages include high complexity relative to MF, and the production of brine that must be processed by the urine processor.

WRM - POTABLE WATER PROCESSING

Baseline Technology

Multifiltration (MF)
+ Low system complexity.
+ Minimal system impacts.
+ Highest water recovery percentage.
- Bed changeout is resupply, crew time penalty (not as high as MF hygiene processor).
- Incapable of removing low molecular weight nonionic organics.

Candidate Substitute Technologies

Reverse Osmosis (RO)
+ Filtration more flexible than contaminant removal using sorbents.
- Requires brine processing by urine processor.
- Incapable of removing almost all groups of low molecular weight organics.
- RO/UF modules appear unnecessary for potable processing. MF posttreatment removes majority of contaminants.

Electrodeionization
- High system complexity relative to RO and MF.
- Requires brine processing by urine processor.
- Pre/posttreatment required.

Waste Management

Baseline Technology

Storage and Biodegradation
All solid waste is stored and returned to earth. Human solid waste is compacted and stored in canisters for biodegradation. When full these canisters are returned to earth and resupplied. This is a very simple, safe, low power method for handling waste, but large logistics penalties are involved. The logical improvement to storage is a waste management system capable of processing waste and recovering its useful constituents, an important step in developing a closed ECLSS. Storage and/or venting has been the method for waste management on all past manned space missions.

Candidate Substitute Technologies

Supercritical Water Oxidation (SCWO)
SCWO is a process in which oxygen and water above its supercritical temperature and pressure (705°F and 3190 psi) are used to oxidize organic waste materials without the presence of a catalyst. When water becomes supercritical its properties as a solvent change. Organic compounds, normally insoluble in water at standard temperature and pressure, become soluble in supercritical water. If sufficient oxygen is available and the reactor temperature and pressure are sufficiently high (750-1200°F and 3675 psi), these organic compounds, along with process atmospheric and trace contaminant gases, are completely oxidized to CO_2, H_2, and N_2. Additionally, inorganic salts become insoluble in supercritical water and precipitate from solution. Efficient processing is achieved with reactor residence times as low as one minute.
SCWO can handle all types of organic spacecraft waste, in addition to processing condensate, wash, and urine/flush waters. SCWO produces potable water from all input waste waters, creating an entirely potable water supply. The process is not applicable to wastes that are composed primarily of inorganics. SCWO is a safety hazard due to its extremely high operating temperatures and pressures, and it is a corrosive process, presenting material and mechanical reliability problems. A posttreatment is required to handle toxic product gases (such as carbon monoxide). SCWO technology is still under development.

WM - WASTE MANAGEMENT

Baseline Technology

Storage and Biodegradation
+ Very simple and safe technology.
+ Low power consumption.
- High logistics penalties.

Candidate Substitute Technologies

Supercritical Water Oxidation (SCWO)
+ Multifunction technology.
+ Handles a wide variety of organic wastes.
- Posttreatment required to handle toxic gases.
- Safety hazard. Reactor operates at extremely high operating temperature and pressure.
- Corrosive process, presenting material and mechanical reliability problems.
- Consumes O_2.
• Technology requires further development.

Waste Management

Wet Oxidation (WETOX)
Wet oxidation refers to the aqueous phase oxidation of organic materials achieved by interacting air with liquid waste in a high temperature, high pressure ($550°F$, 2200 psi) reactor. Liquid water catalyzes oxidation, allowing reactions to proceed at temperatures lower than those required for oxidation by open flame combustion. Additionally, water moderates oxidation rates by providing a medium for heat transfer and by removal of excess heat by evaporation. Oxidation products are innocuous, primarily consisting of carbon dioxide and water, although oxidation is not as complete as in the SCWO process. WETOX effluent requires posttreatment by catalytic oxidation and may also require a phase change water recovery system for additional posttreatment. The WETOX process consumes oxygen, is a corrosive process and is a safety hazard due to its high pressure and temperature operation. Research on WETOX recently has centered on industrial applications. Further effort is required to develop a system for space environments.

Waste Management - Water System (WM-WS or RITE)
The WM-WS system recovers water from brine and rejection concentrates generated by other water recovery and waste management technologies. Water recovery from brine reduces the need for water resupply, significantly lowering launch costs. WM-WS uses an evaporator to separate process brine into water vapor and solid waste. The water vapor is catalytically oxidized, then condensed and output to posttreatment. Solid waste is pumped to an incinerator, which produces ash that must be stored and returned to earth. The catalytic oxidizer and incineration units each operate at about $1200°F$.
WM-WS with a posttreatment could eventually be used to process all types of space station waste water, replacing all the phase change and non-phase change technologies used on the baseline station. The WM-WS process is not affected by bacteria or particulates, and exterminates microorganisms much more effectively than existing water recovery technologies (TIMES, VCD, RO, MF). The original WM-WS system employed a plutonium heat source, and was known as the Radio Isotope Thermal Energy (RITE) system. WM-WS requires further development.

Electrochemical Decomposition
Electrochemical waste decomposition is a non-thermal electrolysis process where solid organic waste and urine can be degraded by oxidation at the surface of catalytic electrodes. CO_2, N_2, and O_2 are the oxidation products formed at the cell anode, while H_2 is formed at the cathode. Electrochemical decomposition operates at low temperatures (less than $150°F$) and oxidizes waste without the consumption of atmospheric oxygen. The process also consumes relatively little power. The electrochemical decomposition system has the disadvantage of being susceptible to carbon monoxide poisoning. Electrochemical decomposition is in the early stages of development.

WM - WASTE MANAGEMENT

Wet Oxidation (WETOX)

+ Handles a wide variety of organic wastes.
+ Oxidation products are innocuous.
- May require extensive posttreatment.
- Safety hazard due to high pressure, high temperature operation.
- Corrosive process.
- Consumes O_2.
• Further development is required for space applications.

Waste Management - Water System (WM-WS or RITE)

+ Water recovery from brines results in large long-term cost savings.
+ More efficient than existing water processors at eliminating bacteria and particulates from waste stream.
+ May become capable of processing all types of space station waste water.
- Requires posttreatment.
• Technology requires further development.

Electrochemical Decomposition

+ High temperatures, pressures not required.
+ Relatively low power consumption.
+ Produces oxygen instead of consuming it.
- Presence of carbon monoxide tends to poison system.
• New technology requiring further development.

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TECHNOLOGY SUMMARY

395

Atmosphere Revitalization (AR):

CO2 Removal
Four-Bed Molecular Sieve (4BMS)
Solid Amine Water Desorbed (SAWD)
Electrochemical Depolarized Concentrator
    (EDC)
Air Polarized Concentrator (APC or EDC
    w,wo/H2)
Two-Bed Molecular Sieve (2BMS)
Membranes

CO2 Reduction
Bosch Reactor
Sabatier Reactor
Advanced Carbon Reactor (ACR)
CO2 Electrolysis

O2 Generation
Static Feed Water Electrolysis (SFWE)
Liquid Anode Feed Solid Polymer Electrolysis
    (SPE)
CO2 Electrolysis
Water Vapor Electrolysis (WVE)

Trace Contaminant Control
Carbon Adsorption Beds with Catalytic Oxidizer
Reactive Bed Plasma (RBP)

Water Recovery and Management (WRM):

Urine Processing
Thermoelectric Integrated Membrane
    Evaporation Subsystem (TIMES)
Vapor Compression Distillation (VCD)
Air Evaporation System (AES)
Vapor Phase Catalytic Ammonia Removal
    (VPCAR)

Hygiene Water Processing
Reverse Osmosis (RO)
Multifiltration (MF)

Potable Water Processing
Multifiltration (MF)
Reverse Osmosis (RO)
Electrodeionization

Waste Management (WM):

Storage and Biodegradation
Supercritical Water Oxidation (SCWO)
Wet Oxidation (WETOX)
Waste Management - Water System (WM-WS
    or RITE)
Electrochemical Decomposition

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ECLSS TECHNOLOGY SCHEMATICS, PROCESS DIAGRAMS, AND FLUID INTERFACES

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CO₂ REMOVAL
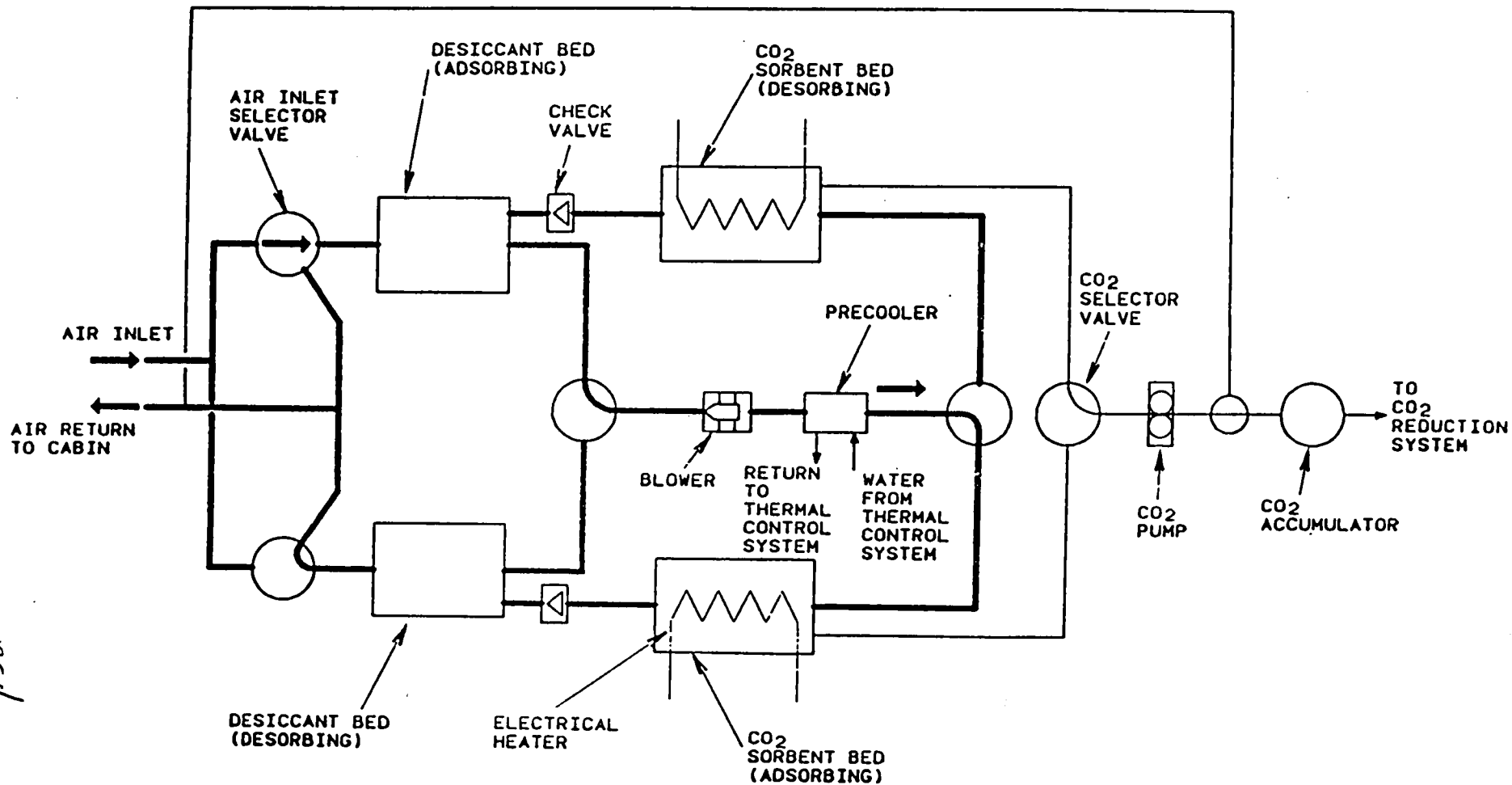
Four-Bed Molecular Sieve System Component Integration

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Solid Amine Water Desorbed Process Diagram

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402
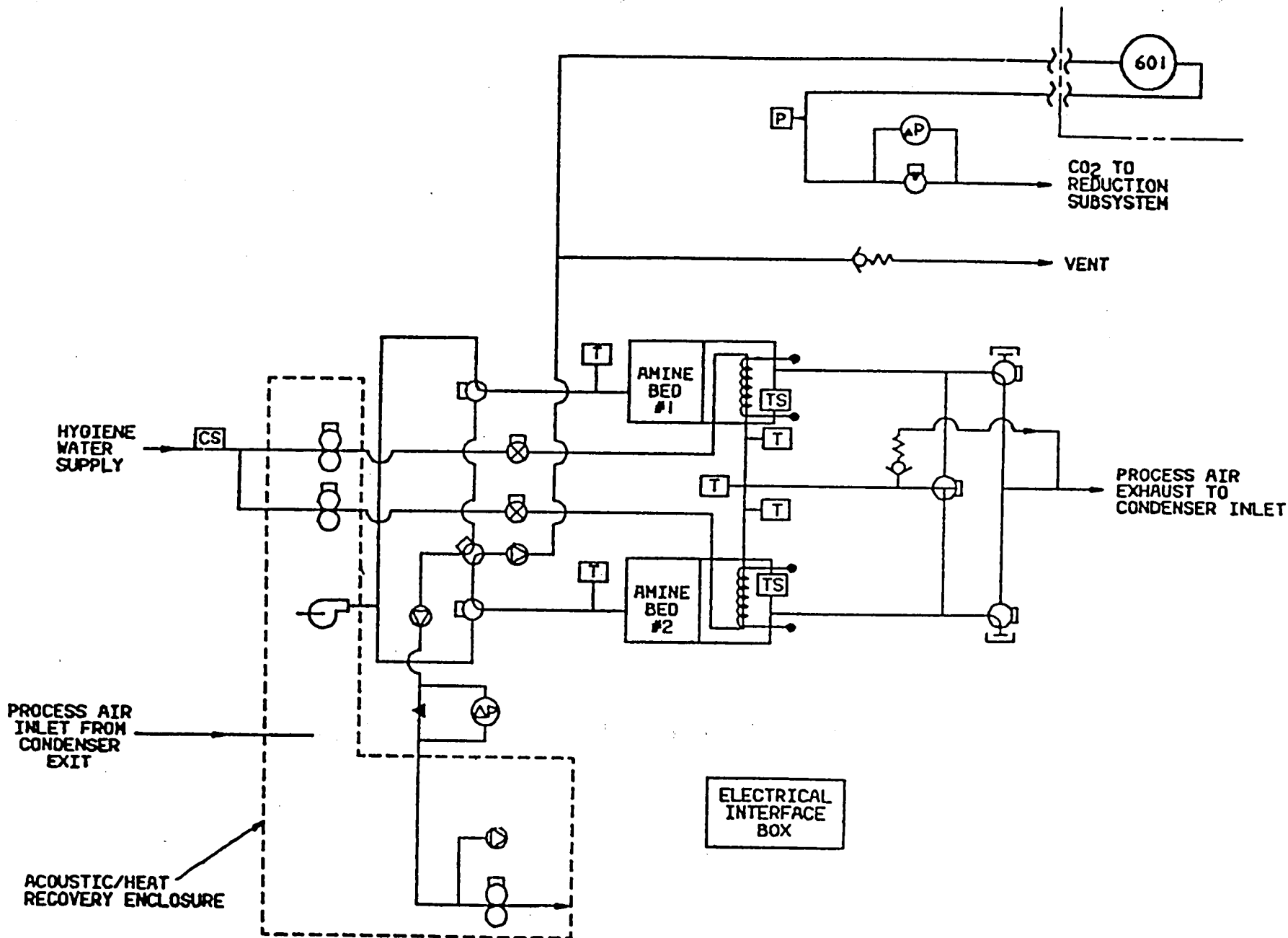
Solid Amine Water Desorbed Mechanical Schematic

CO2 TO
REDUCTION
SUBSYSTEM

VENT

AMINE
BED
#1

AMINE
BED
#2

HYGIENE
WATER
SUPPLY

PROCESS AIR
EXHAUST TO
CONDENSER INLET

PROCESS AIR
INLET FROM
CONDENSER
EXIT

ELECTRICAL
INTERFACE
BOX

ACOUSTIC/HEAT
RECOVERY ENCLOSURE

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Power to
External Load

H_2/CO_2 To Vent
or CO_2 Reduction

Purified Air

Coolant

Anode Reactions:

$$2H_2 + 4OH^- = 4H_2O + 4e^-$$
$$2CO_3^= + 2H_2O = 4OH^- + 2CO_2$$

Cathode Reactions:

$$O_2 + 2H_2O + 4e^- = 4OH^-$$
$$4OH^- + 2CO_2 = 2H_2O + 2CO_3^=$$

Air with CO_2

Liquid Coolant

H_2

Overall

$$2 CO_2 + 2 H_2 + O_2 = 2 H_2O + 2 CO_2 + \text{Electric Power} + \text{Heat}$$

Electrochemical Depolarized Concentrator Process and Reactions

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406
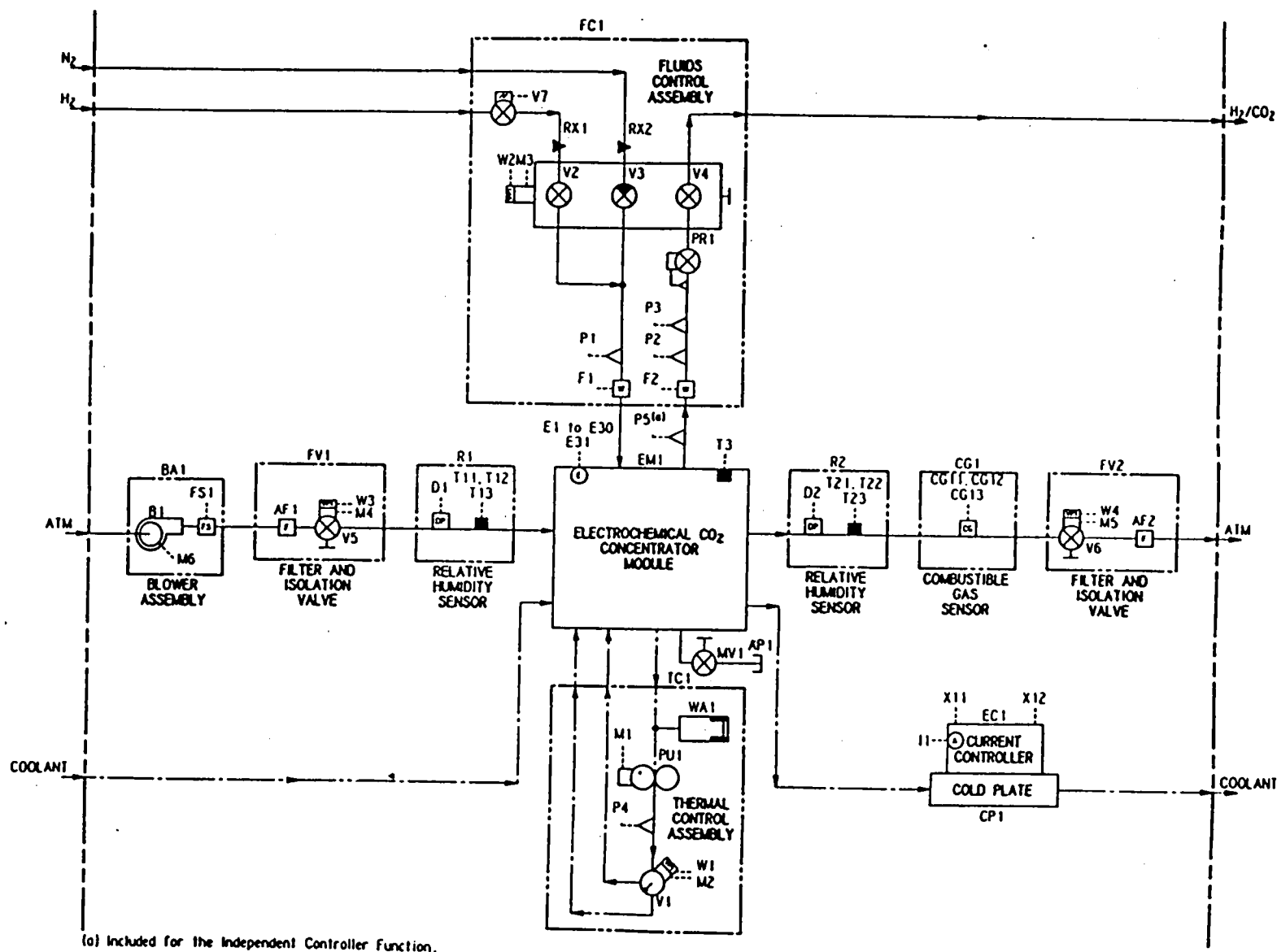
Electrochemical Depolarized Concentrator System Schematic with Sensors

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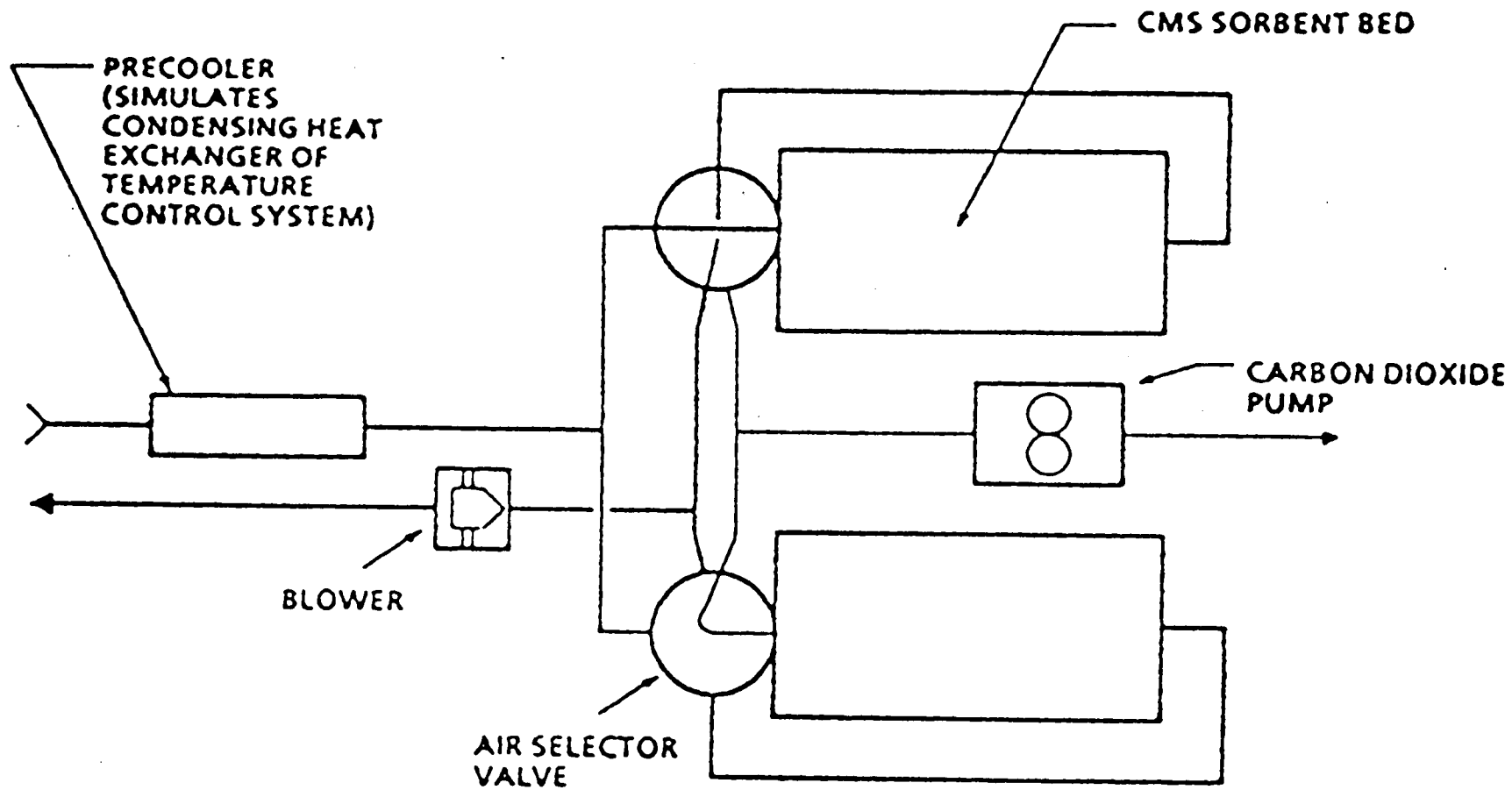
Two-Bed Molecular Sieve Basic Schematic

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410

CO₂ REDUCTION

Bosch Reactor

Overall Reaction:
$$CO_2 + 2H_2 = 2H_2O + C + Heat$$

$Heat = 975$ Btu/lb CO_2

Condenser/ Separator

Water

Feed Gases - H_2 and CO_2

Compressor

Recuperative Heat Exchanger

Heater

Insulation
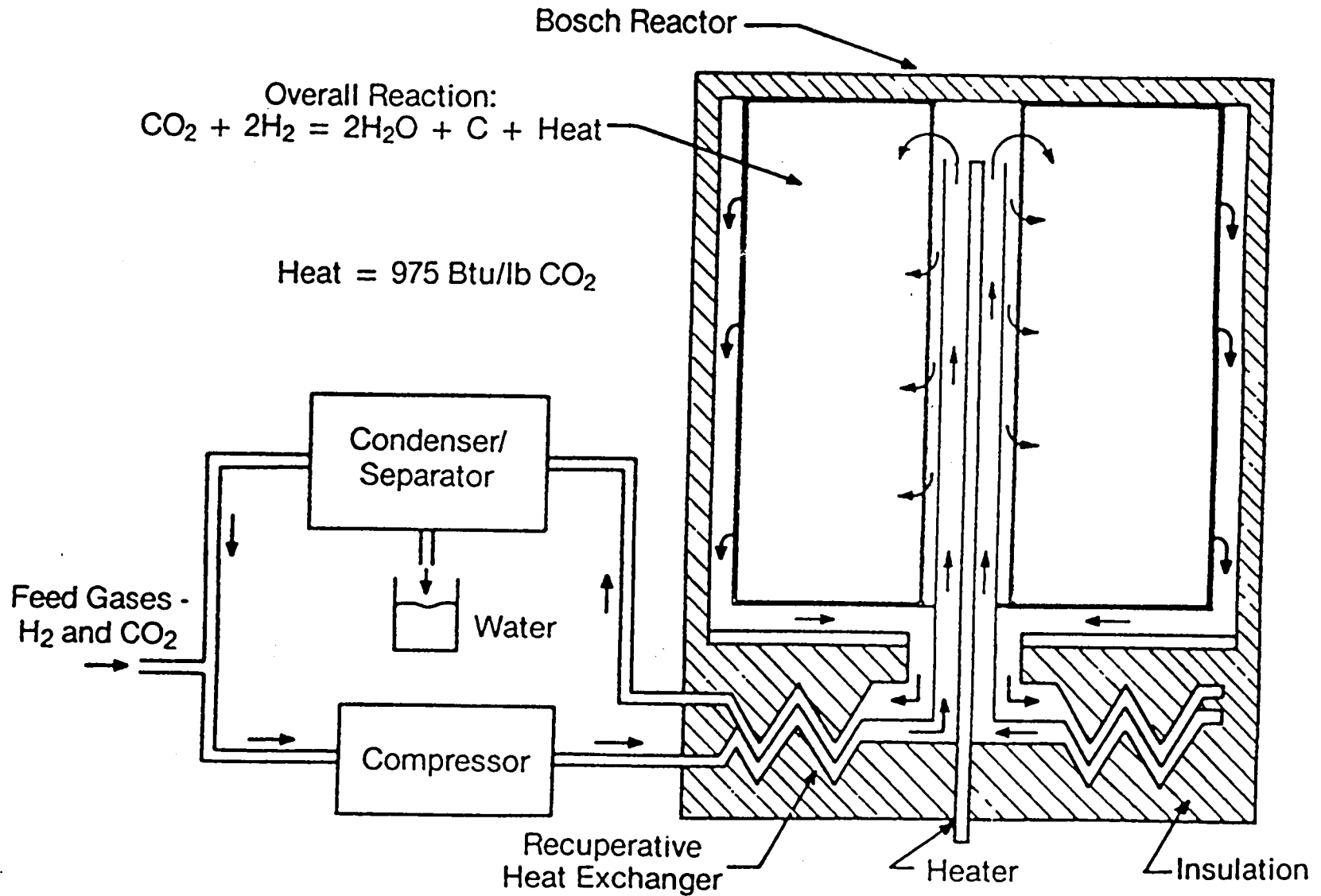
Bosch Process Schematic

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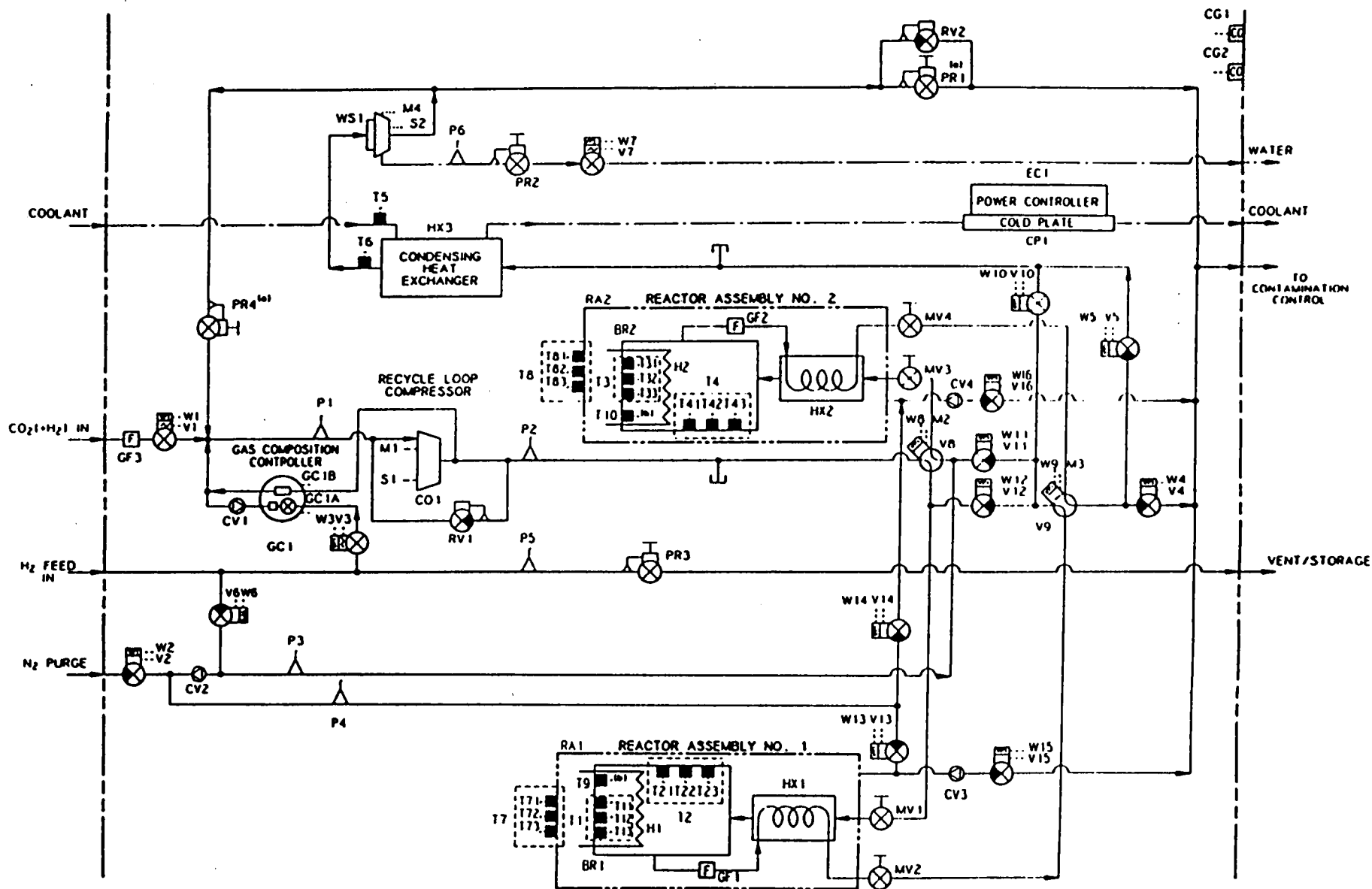
(a) Required for Non-EDC CO₂ Concentrator Interface Only

(b) Sensors Used for SDSU Only.
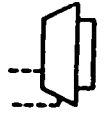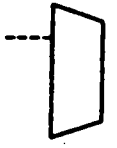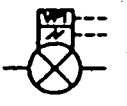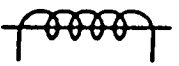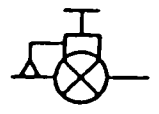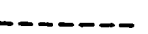
Bosch Mechanical Schematic with Sensors

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WATER SEPARATOR

COMPRESSOR

HEATER. ELECTRICAL

HEAT EXCHANGER. REGENERATIVE

SAMPLING OR ACCESS PORT. CAPPED

SENSOR. PRESSURE

SENSOR. TEMPERATURE

SENSOR. COMBUSTIBLE GAS

SENSOR. CARBON MONOXIDE

FILTER

VALVE. MOTOR DRIVEN 4-WAY WITH VALVE POSITION INDICATOR

VALVE. ELECTRICAL SHUTOFF (N/C) WITH VALVE POSITION INDICATOR

VALVE. ELECTRICAL SHUTOFF (N/C) ENERGIZED OPEN WITH VALVE POSITION INDICATOR

VALVE. ELECTRICAL SHUTOFF (N/O) DE-ENERGIZED WITH VALVE POSITION INDICATOR

REGULATOR. PRESSURE WITH MANUAL ADJUSTMENT

VALVE. RELIEF

VALVE. CHECK

GAS LINE

LIQUID LINE

ELECTRICAL LINE

Bosch Schematic Legend

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416
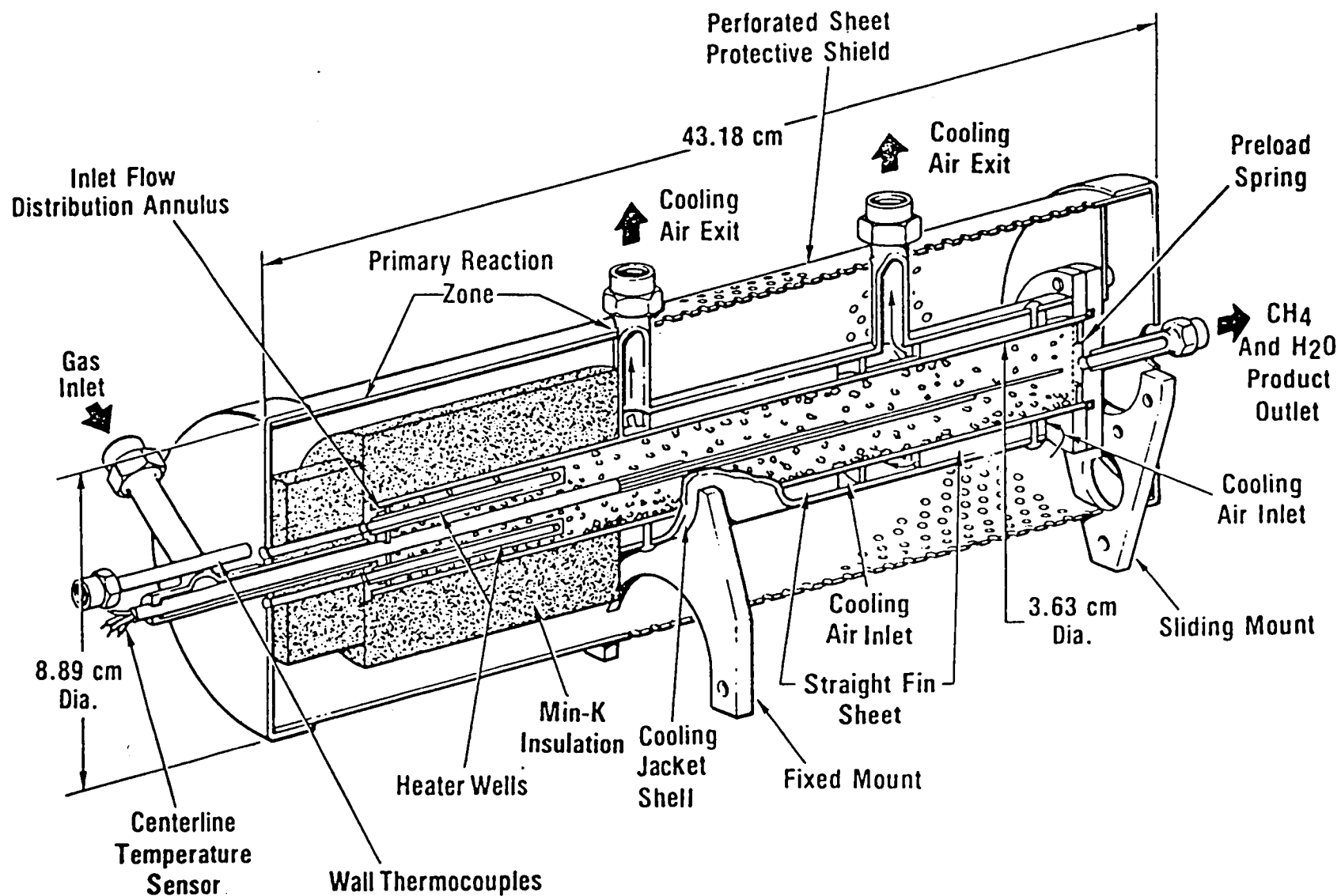
Cross Section of Sabatier Methanation Reactor

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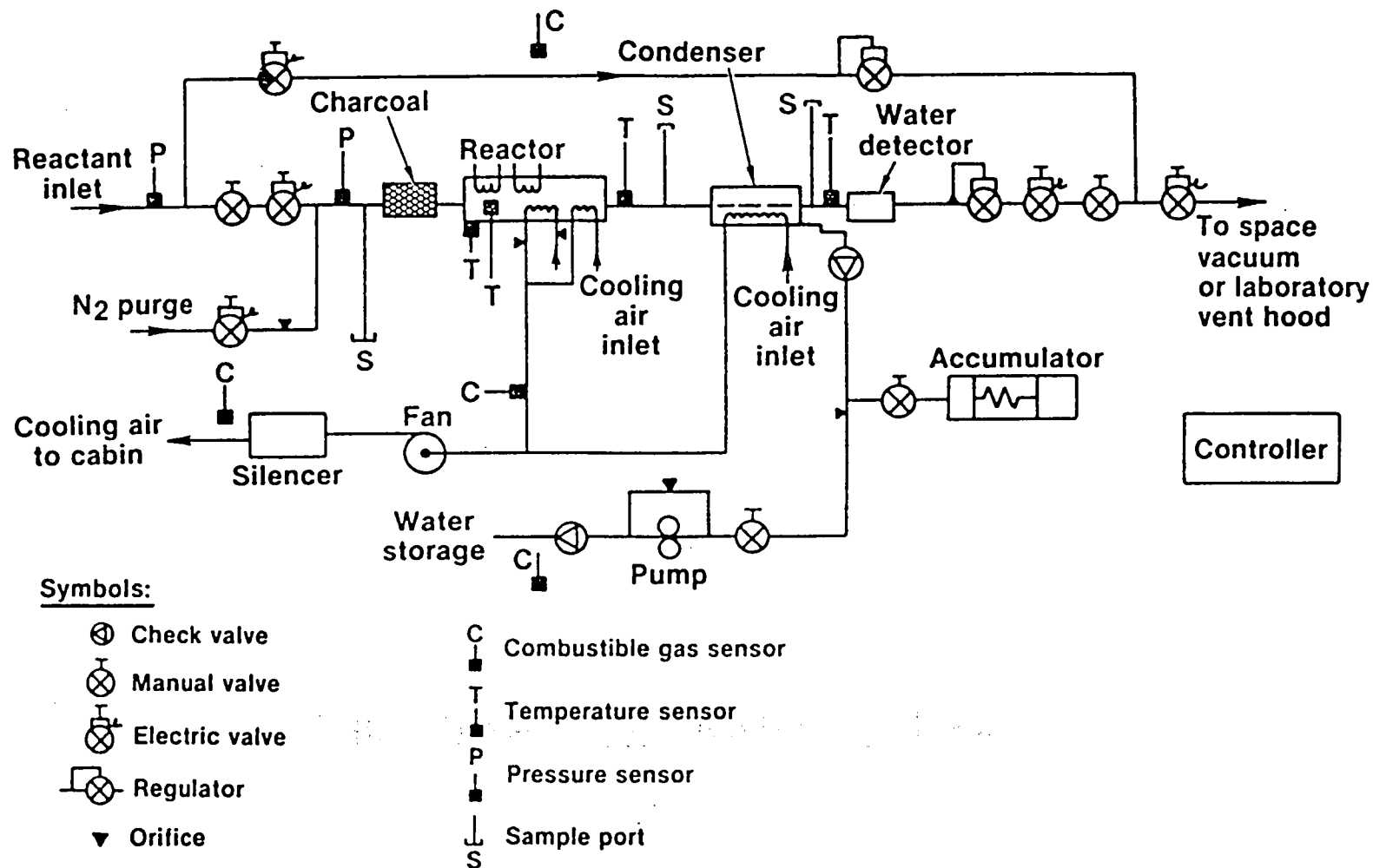
Sabatier System Schematic

Symbols:

- ⊘ Check valve
- ⊗ Manual valve
- ⊗ Electric valve
- ⊐⊗⊢ Regulator
- ▼ Orifice

C — Combustible gas sensor

T — Temperature sensor

P — Pressure sensor

S — Sample port

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420

CO₂ (& H₂) ... **H₂**

CO₂ (& H₂) (1 mole)

H₂ (2 moles)

CO₂/H₂

On-line carbon formation reactor

Off-line carbon formation reactor

CH₄ (1 mole)

Regulated H₂ flow (2 moles)

H₂: CO₂ @ 4 moles: 1 mole

Sabatier reactor

CH₄

H₂O (gas & vapor)

Condenser

CH₄

H₂O (liquid)

Water separator

H₂O (liquid)
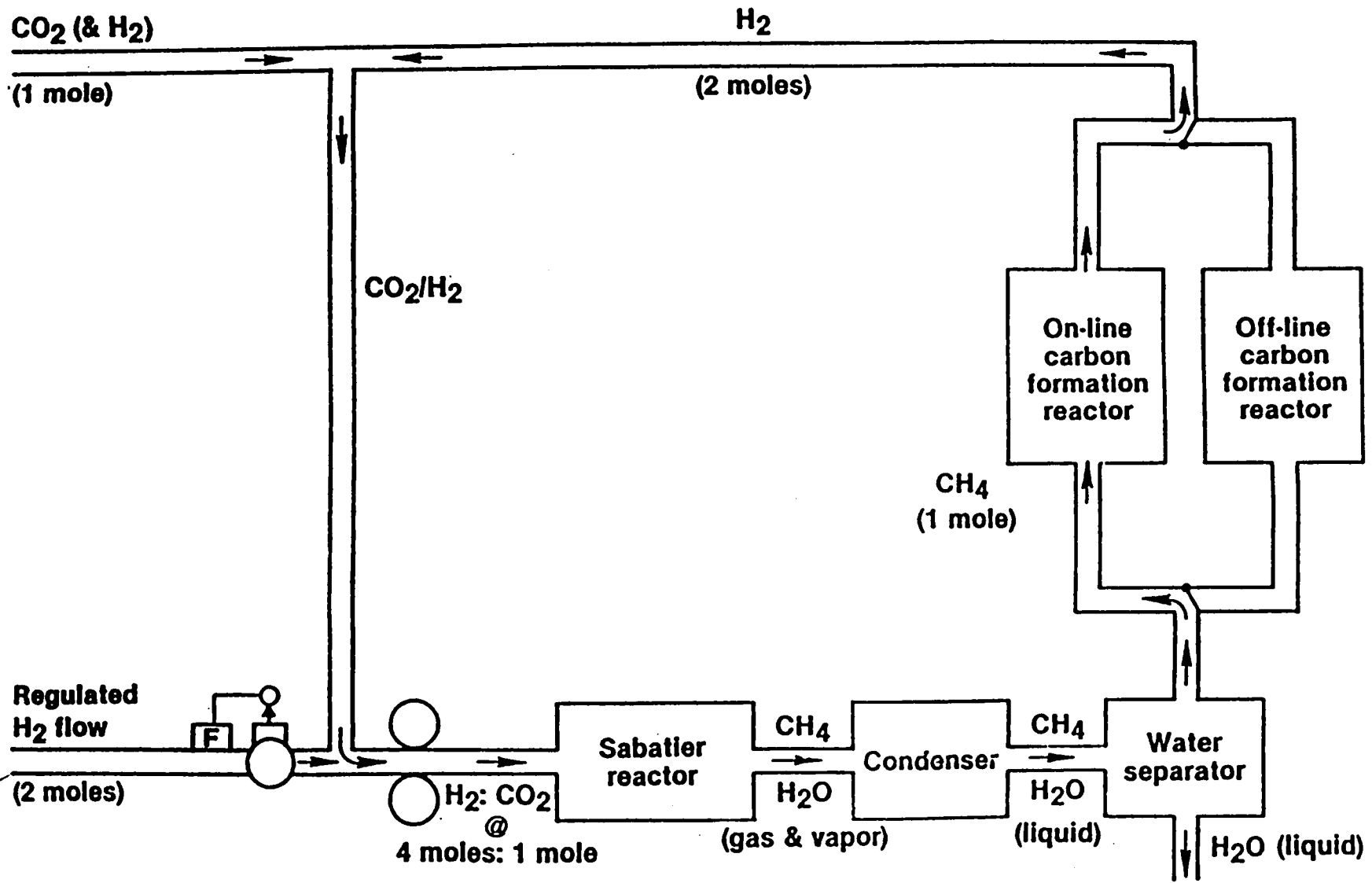
Advanced Carbon Reactor Process Schematic

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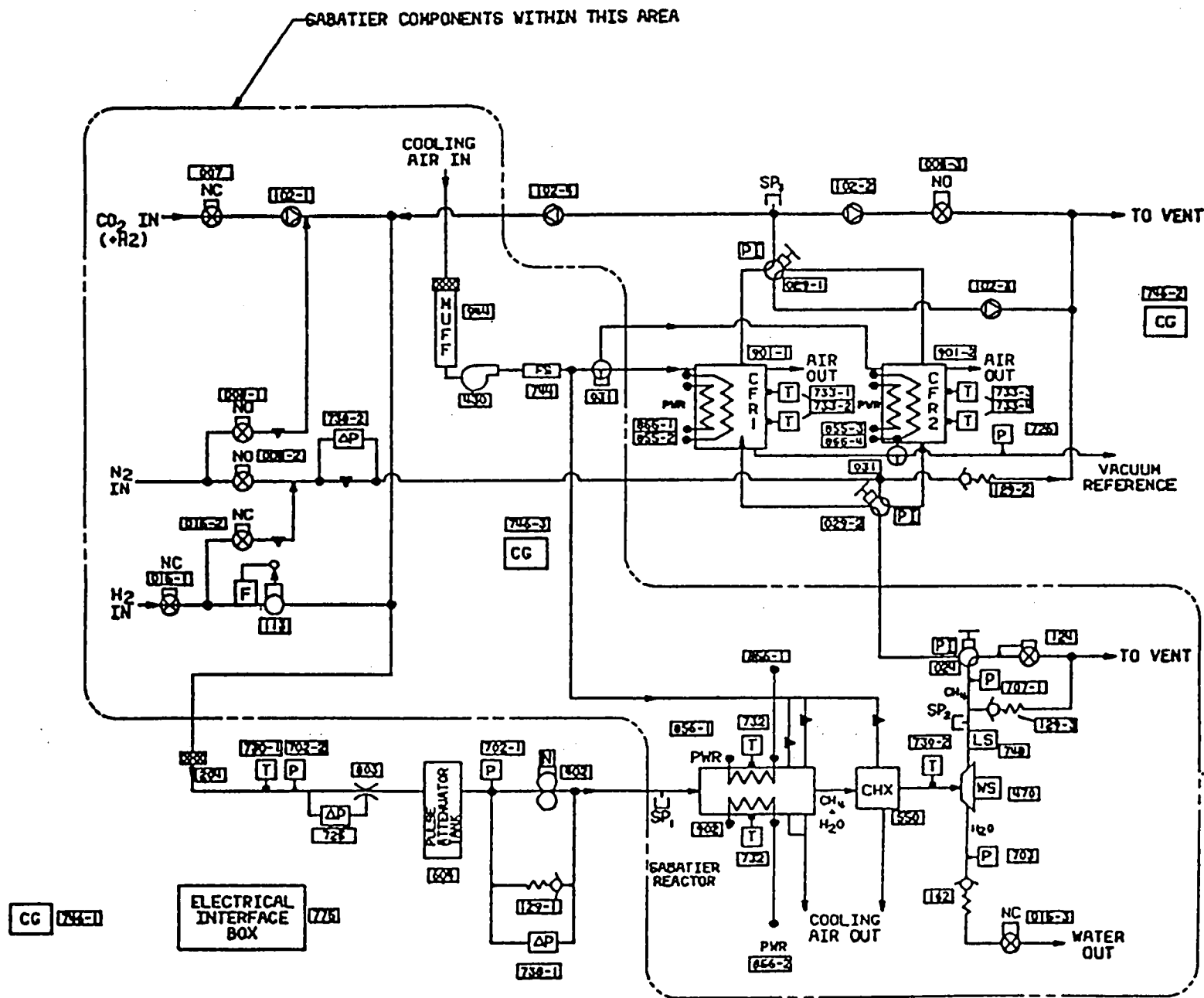
Advanced Carbon Reactor Mechanical Schematic

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CO$_2$ REDUCTION

FLUID INTERFACES

425

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Bosch Reactor	Liquid Coolant, H$_2$ N$_2$ Purge, CO$_2$	N$_2$ Purge Vent Water to Potable Processor H$_2$ Vent Liquid Coolant
Sabatier Reactor	CO$_2$, H$_2$ Avionics Air	Water to Potable Processor Vent to Storage Avionics Air
Advanced Carbon Reactor	CO$_2$, H$_2$ Avionics Air, N$_2$	Water to Potable Processor Avionics Air N$_2$ Purge Vent, H$_2$ Vent Vacuum (for vacuum jacket)
CO$_2$ Electrolysis	CO$_2$, N$_2$ Avionics Air	O$_2$, H$_2$ Vent CO/CO$_2$ to Carbon Deposition Reactor Avionics Air

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O₂ GENERATION

Static Feed Water Electrolysis Cell and Reactions

Power Supply

e⁻

e⁻

H₂

O₂

Reactions

Electrolyte & Retention Matrix

Water Feed Membrane

O₂

H₂

H₂O

H₂O

Anode (+): $4OH^- \longrightarrow O_2 + 2H_2O + 4e^-$

Cathode (-): $4H_2O + 4e^- \longrightarrow 2H_2 + 4OH^-$

Overall: $2H_2O + Power \longrightarrow 2H_2 + O_2$

427

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429

(a) Used by Sensor Dedicated Shutdown Unit (SDSU).

Static Feed Water Electrolysis Mechanical Schematic

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VALVE. MOTOR DRIVEN SHUTOFF (OPEN)
WITH VALVE POSITION INDICATOR

SENSOR. PRESSURE

VALVE. MOTOR DRIVEN SHUTOFF (CLOSED)
WITH VALVE POSITION INDICATOR

SENSOR. COMBUSTIBLE GAS

VALVE. ELECTRICAL SHUTOFF (N/C)
ENERGIZED OPEN
WITH VALVE POSITION INDICATOR

HEATER. ELECTRICAL
WITH THERMOSWITCH

VALVE. ELECTRICAL SHUTOFF (N/O)
ENERGIZED CLOSED
WITH VALVE POSITION INDICATOR

SENSOR. TEMPERATURE

VALVE. RELIEF

ACCESS PORT. CAPPED

CHECK VALVE

SENSOR. VOLTAGE

QUICK DISCONNECT. MALE END
WITH CAP

SENSOR. DIFFERENTIAL PRESSURE

RESTRICTOR

GAS LINE

FILTER

LIQUID LINE

PRESSURE REGULATOR
WITH REMOTE SENSING

PRESSURE REGULATOR. MOTOR ACTUATED
WITH VALVE POSITION INDICATOR

TANK. WATER STORAGE

ACCUMULATOR

Static Feed Water Electrolysis Schematic Legend

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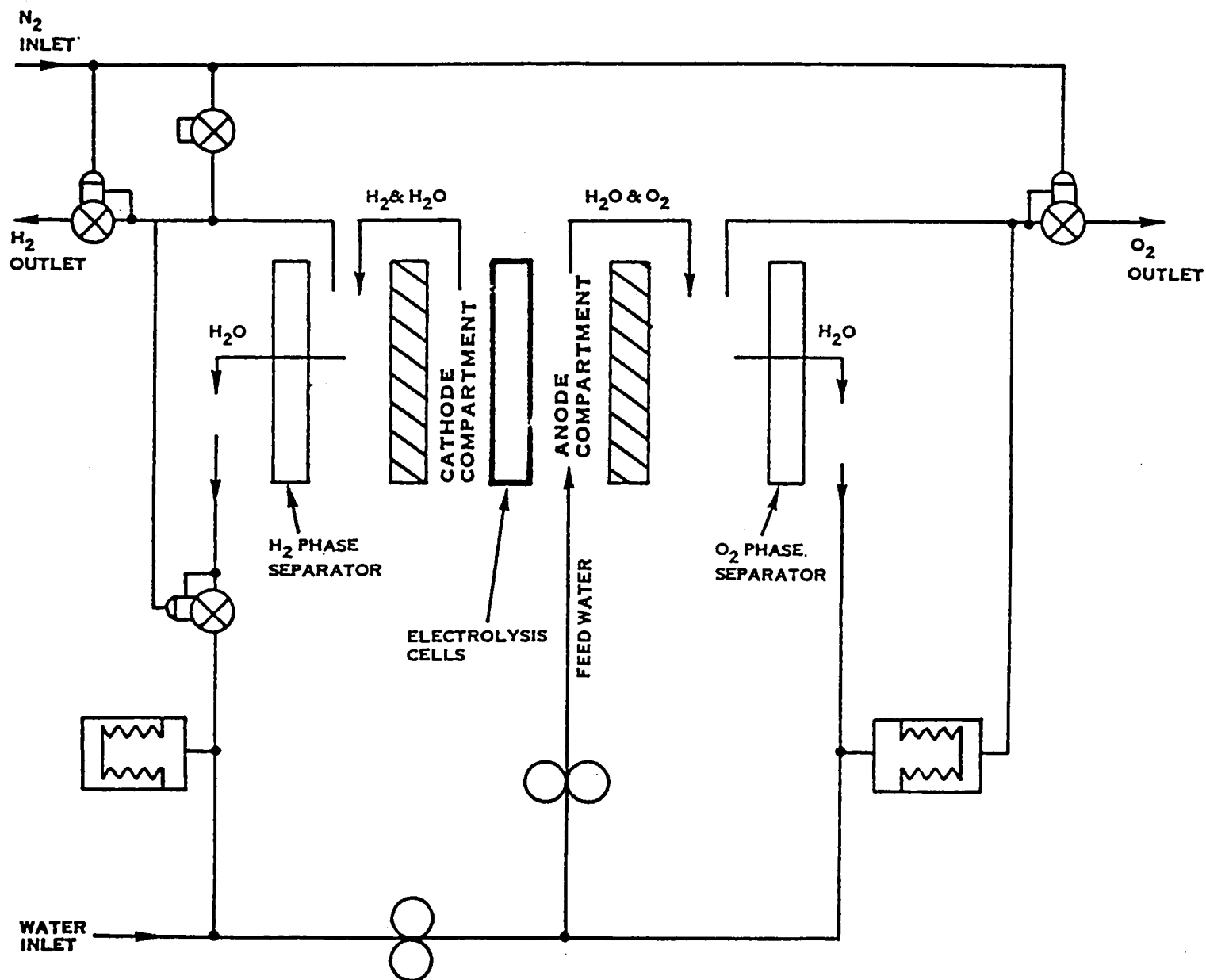
Liquid Anode Feed Solid Polymer Electrolysis Simplified Schematic

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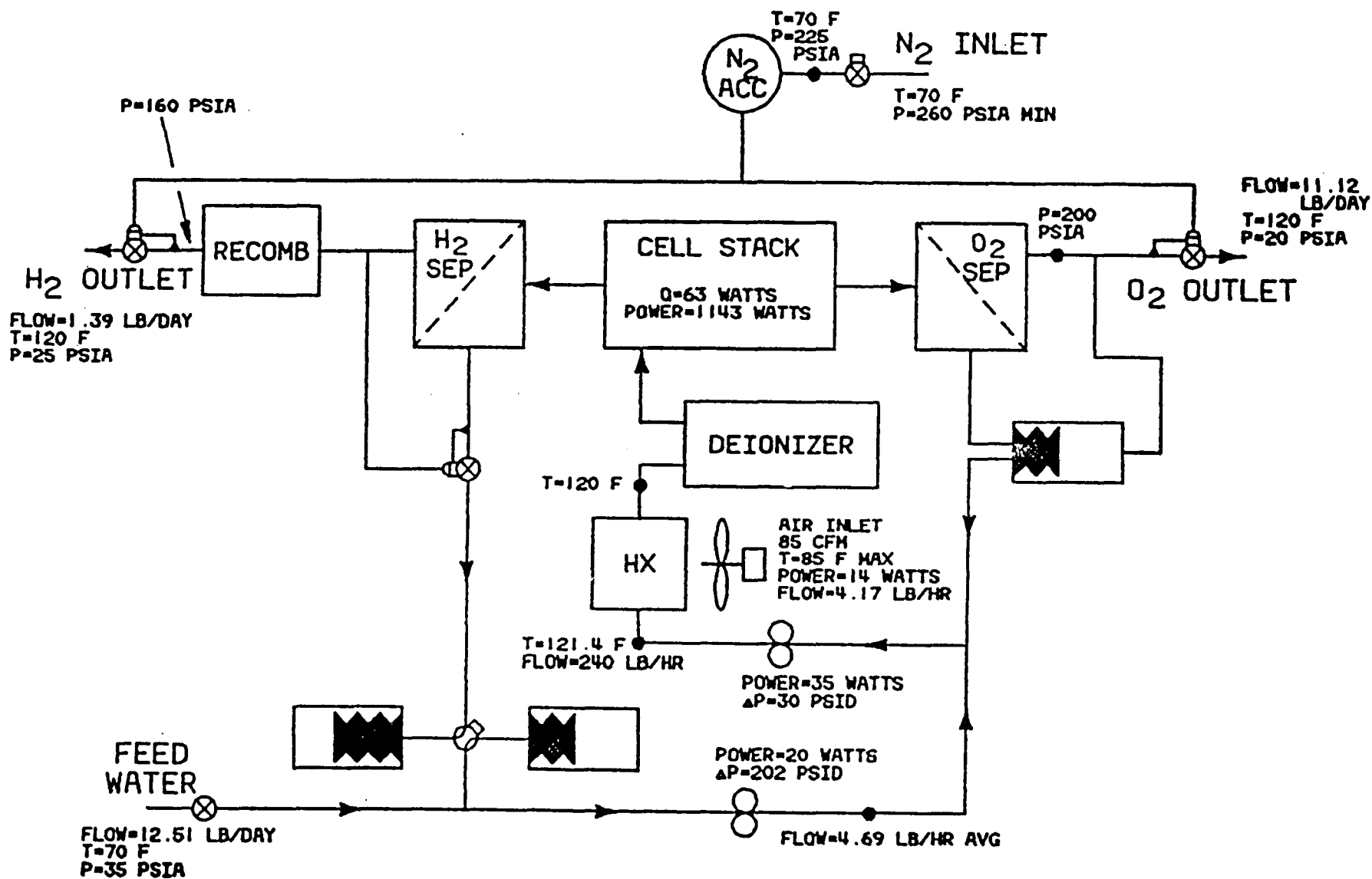
Liquid Anode Feed Solid Polymer Electrolysis Flow Chart

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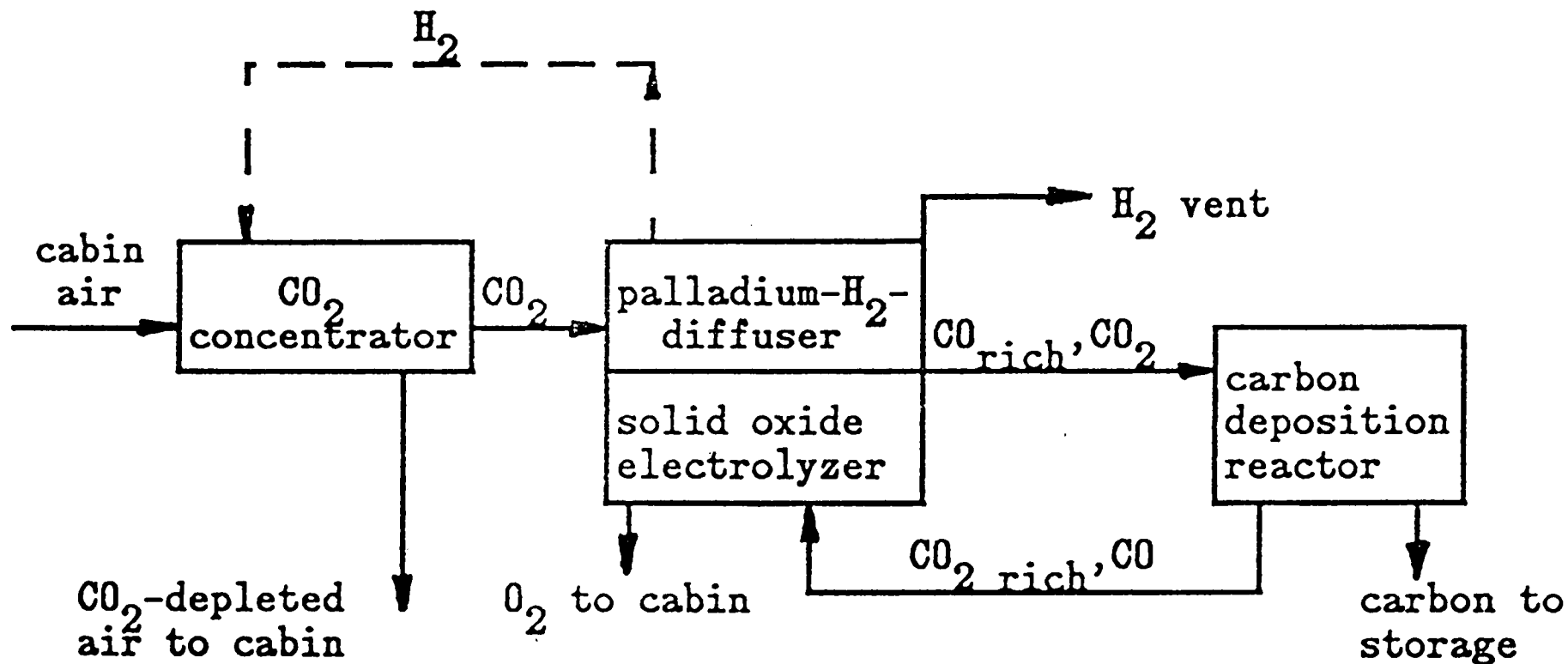
Advanced Concept Oxygen Reclamation Scheme Using CO_2 Electrolysis

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438

1	Cell	
2	Test Fixture	
3	A.C. Power Supply	
4	3-Zone Test Furnace	
5	Oxygen Sensor Inlet	
6	Oxygen Sensor Outlet	
7	Humidifier	
8-11	Gas Inlets for CO_2, CO, H_2, N_2	
12, 13	Spare Gas Inlets	
14	Mass Flow Controllers	
15	Gas Manifold and Valves	
16	Oxygen Pressure Control – Monitor	
17	Mass Flow Meter	
18	Oscilloscope	
19	Electronic Switch and Test Circuitry	
20	D.C. Power Supply	
21	D.C. Current Line	
22	D.C. Potential Line	
23	Data Highway	
24	Data Acquisition	

Essential Components of a Breadboard CO_2 Electrolysis Unit

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The diagram shows:

Power Supply

Cabin Atmosphere with Water Vapor → (into cell)

e^- ↑   ↓ e^-

→ H_2

H_2O

Electrolyte Retention Matrix

H_2

O_2

O_2-Enriched Cabin Atmosphere

Reaction

Cathode (–) : $4H^+ + 4e^- = 2H_2$

Anode (+) : $2H_2O = O_2 + 4H^+ + 4e^-$

Overall   : $2H_2O + \text{Electrical Energy} \longrightarrow 2H_2 + O_2 + \text{Heat}$
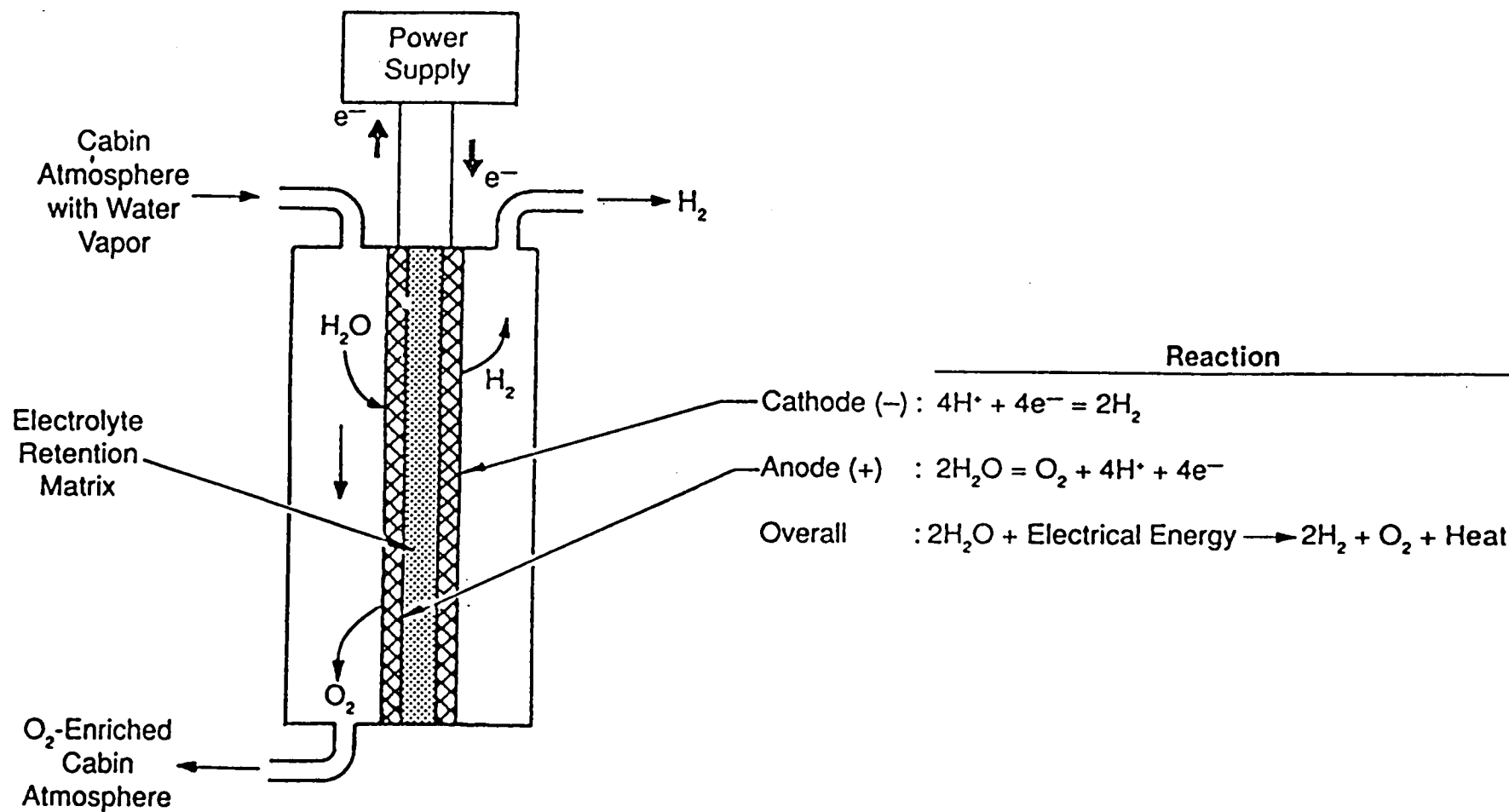
Water Vapor Electrolysis Cell and Reactions

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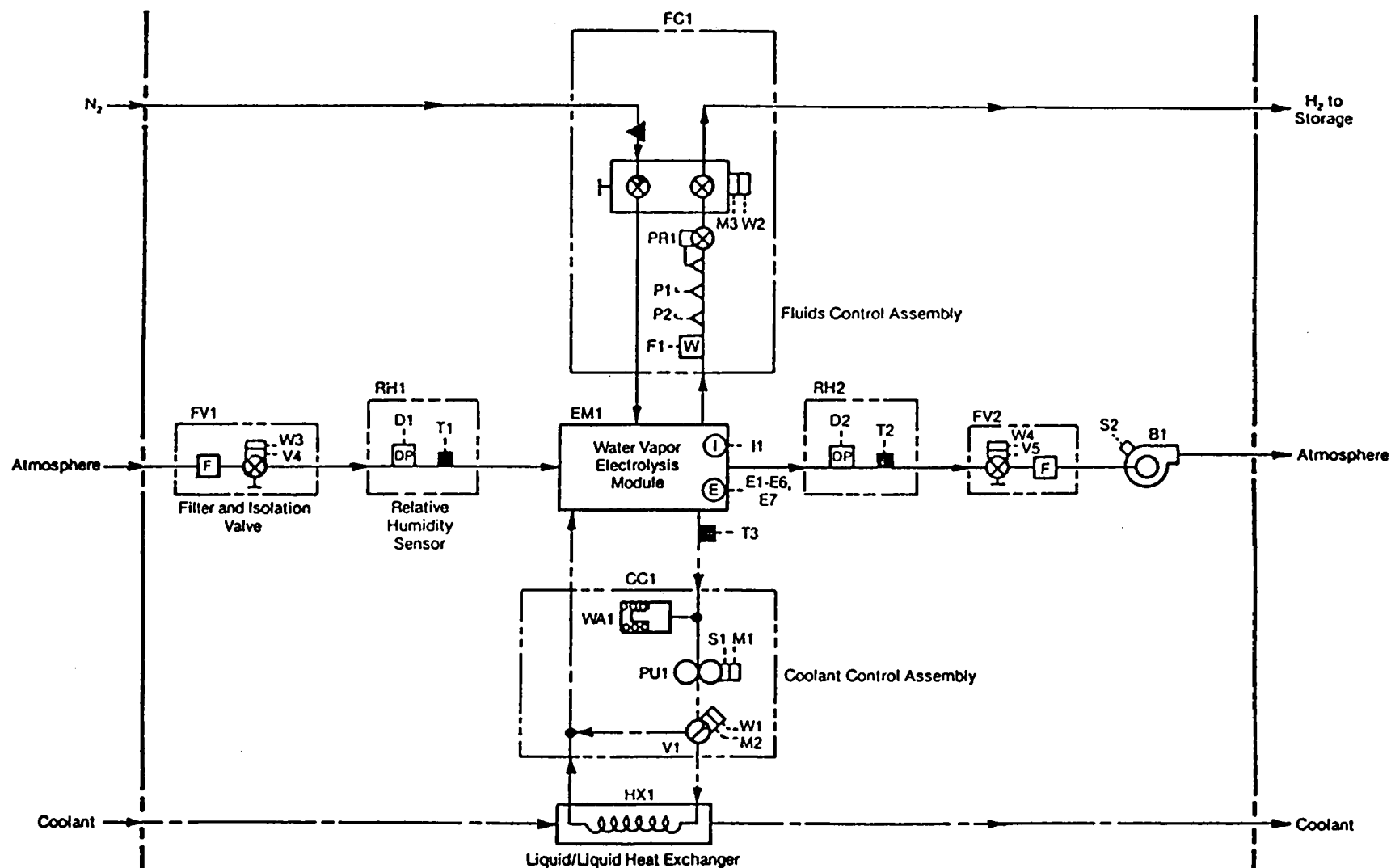
Water Vapor Electrolysis Mechanical Schematic with Sensors

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O$_2$ GENERATION

FLUID INTERFACES

| TECHNOLOGY | FLUID INTERFACES | |
	LINE IN	LINE OUT
Static Feed Water Electrolysis	Hygiene Water N$_2$ (O$_2$ Side) N$_2$ (H$_2$ Side)	O$_2$, H$_2$
Liquid Anode Feed Solid Polymer Electrolysis	Hygiene Water N$_2$, Avionics Air	O$_2$, H$_2$ Avionics Air
Water Vapor Electrolysis	Cabin Air Liquid Coolant	Return Air, H$_2$, Liquid Coolant
CO$_2$ Electrolysis	See CO$_2$ Reduction	

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TRACE CONTAMINANT CONTROL
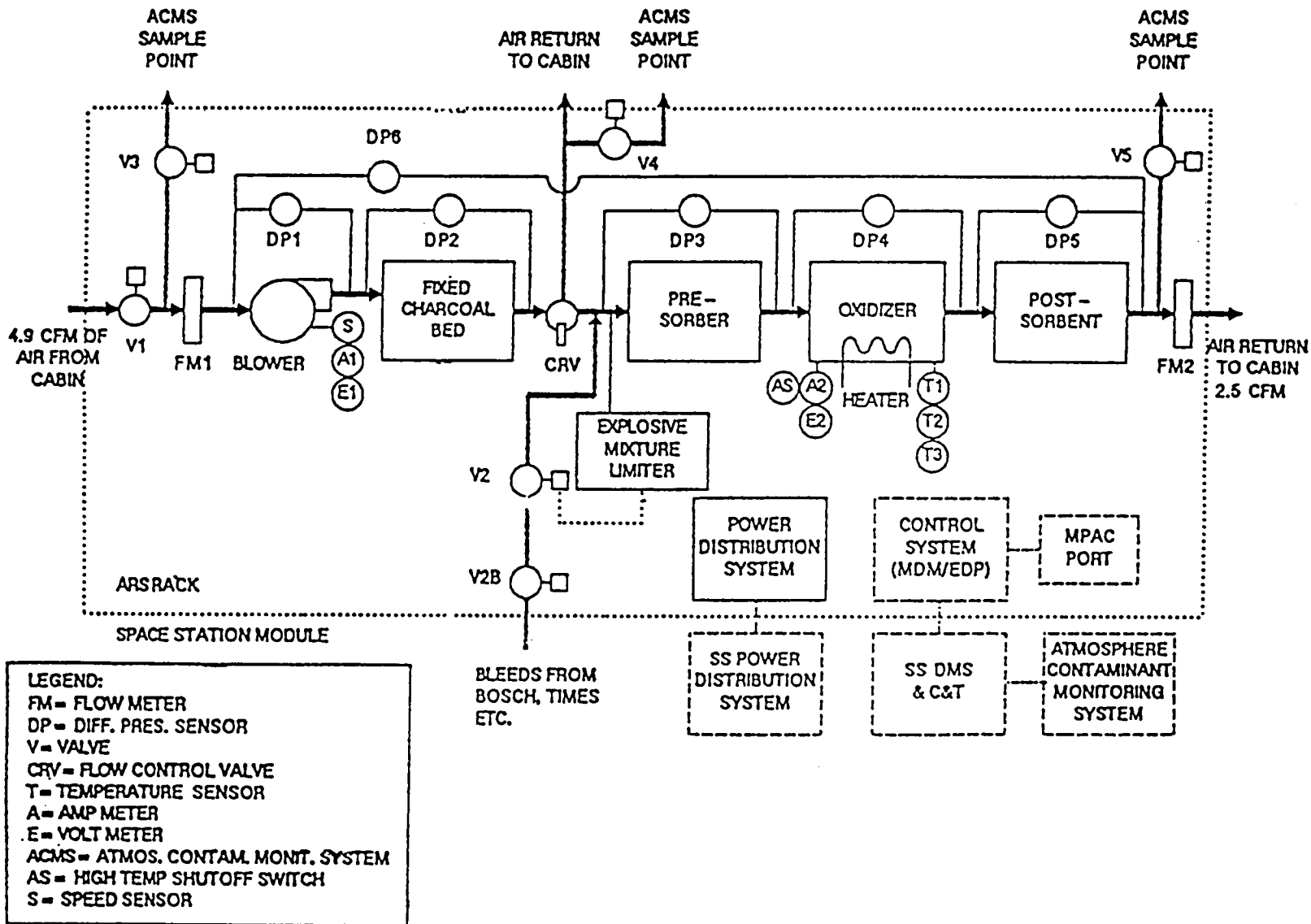
Baselined Trace Contaminant Control System Schematic

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TRACE CONTAMINANT CONTROL

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Expendable Carbon Beds with Catalytic Oxidizer	Cabin Air Avionics Air	Return Air Avionics Air
Reactive Bed Plasma	Cabin Air	Return Air

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URINE PROCESSING

451

PROCESSING SECTION

FACILITY COLLECTION SECTION

WASTEWATER IN

PRETREAT UNIT

WASTE STORAGE

HOLLOW FIBER MEMBRANE EVAPORATOR

STEAM

THERMOELECTRIC HEAT PUMP

WASTEWATER HEAT EXCHANGER

RECYCLE PUMP

CONDENSER

CONDENSATE LIQUID/GAS SEPARATOR

FACILITY POSTFILTRATION SECTION

POTABLE WATER
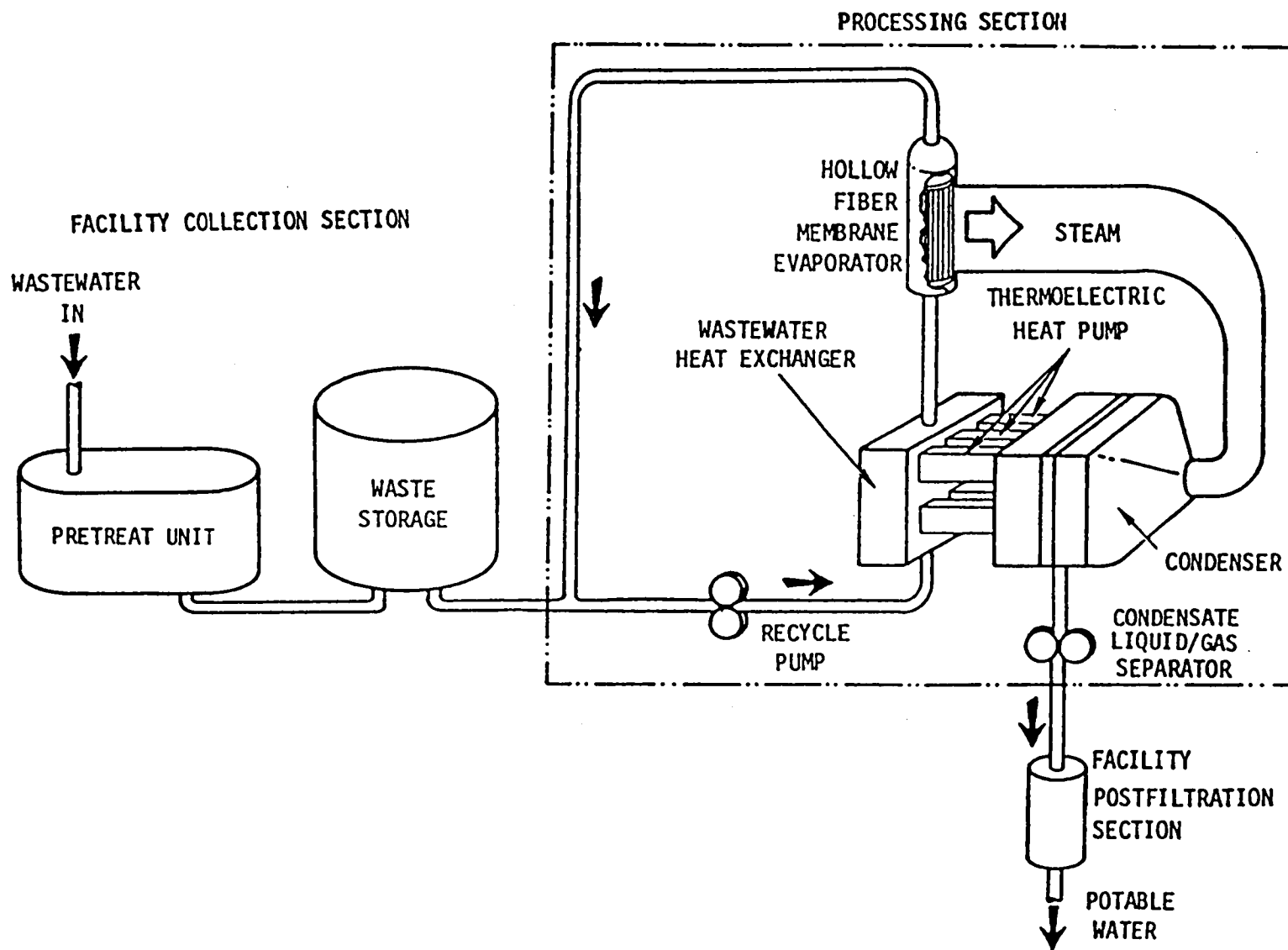
Thermoelectric Integrated Membrane Subsystem Process Schematic

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Legend:

- DUAL PROBE
- PI — POSITION INDICATOR
- ORIFICE
- MCV-H — MICROBIAL CHECK VALVE HIGH I_2
- ΔP — PRESSURE DIFF SENSOR
- P — PRESSURE SENSOR
- T — TEMPERATURE SENSOR
- TEST PORT
- POWER
- CS — CONDUCTIVITY SENSOR
- NO — NORMALLY OPEN WITH LOSS OF POWER
- NC — NORMALLY CLOSED WITH LOSS OF POWER
- FILTER
- PUMP OR COMPRESSOR
- FAN
- HX — HEAT EXCHANGER
- THREE WAY VALVE, ELECTRICALLY ACTUATED
- ELECTRIC SO VALVE
- RELIEF VALVE
- CHECK VALVE
- TED — THERMO-ELECTRIC DEVICE

LEGEND

Thermoelectric Integrated Membrane Subsystem Mechanical Schematic

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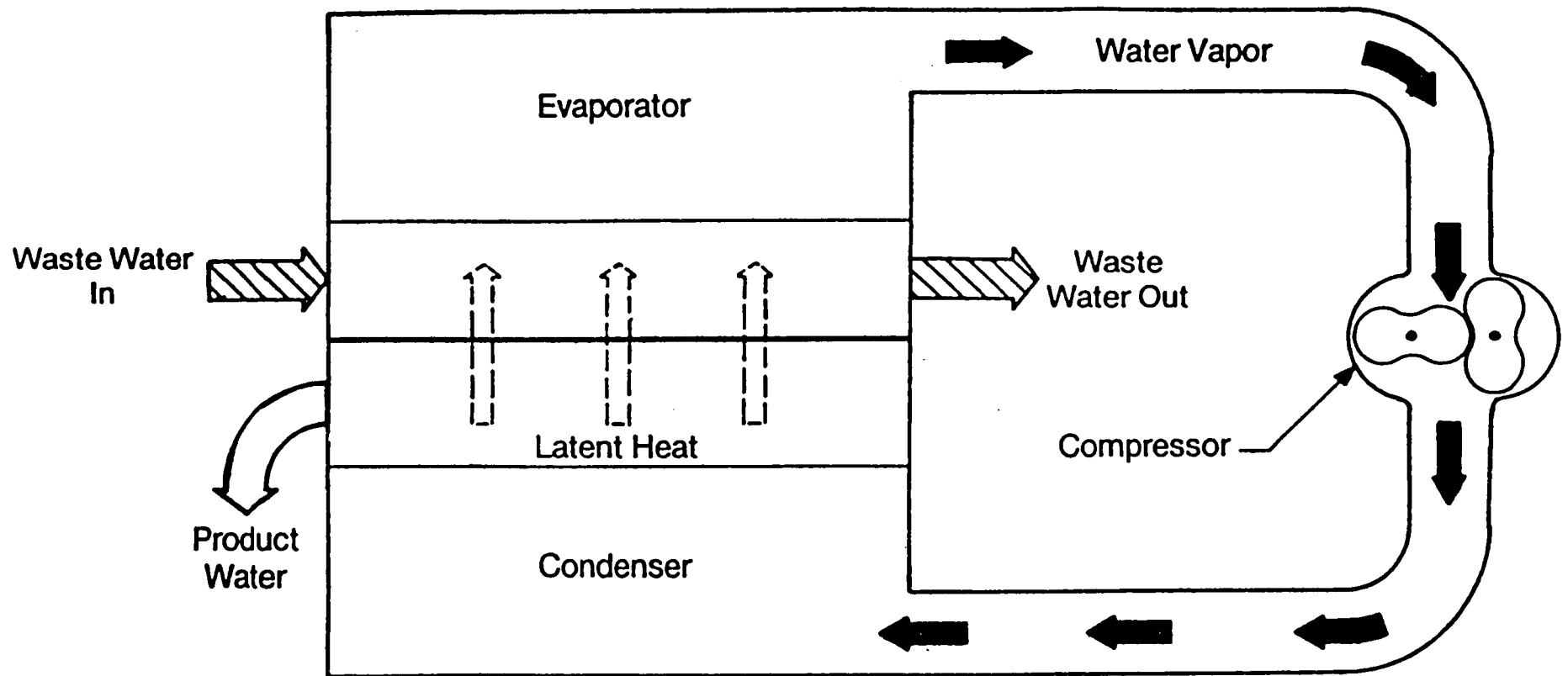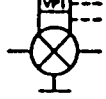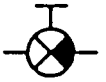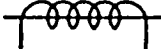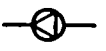
Vapor Compression Distillation Process Schematic

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Vapor Compression Distillation Mechanical Schematic

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	MOTOR ACTUATOR		MICROBIAL AIR FILTER
	SAMPLING OR ACCESS PORT, CAPPED		VALVE, MICROBIAL CHECK
	SENSOR, CONDUCTIVITY		VALVE, MOTOR DRIVEN NORMALLY CLOSED WITH MANUAL OVERRIDE AND VALVE POSITION INDICATOR
	SENSOR, DIFFERENTIAL PRESSURE		VALVE, MOTOR DRIVEN NORMALLY OPEN WITH MANUAL OVERRIDE AND VALVE POSITION INDICATOR
	SENSOR, LIQUID		VALVE, THREE-WAY MOTOR DRIVEN WITH MANUAL OVERRIDE AND VALVE POSITION INDICATOR
	SENSOR, PRESSURE		VALVE, MANUAL SHUTOFF NORMALLY OPEN
	SENSOR, SPEED		VALVE, MANUAL SHUTOFF NORMALLY CLOSED
	SENSOR, TEMPERATURE		HEAT EXCHANGER, REGENERATIVE
	VALVE, CHECK		VALVE, RELIEF
	COUPLING, QUICK DISCONNECT		HOSE, FLEXIBLE

Vapor Compression Distillation Schematic Legend

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TREATED URINE

AIR EVAP. PROCESSOR INTERFACE

DRY AIR

WICK EVAPORATOR

MOIST AIR

FAN

ΔP

P

ELECTRICAL HEATER

CONDENSER ASSEMBLY

COOLING H2O (40°F)

H2O CONDENSER

TO CONTROLLER

SLURPER

CONDENSATE STREAM TO SEPARATOR

AIR RETURN FROM SEPARATOR

Air Evaporation System Schematic

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462

Condensate
Collector

Product Pump

Sensor

HX

N_2O
Decomposition
Reactor

HTR

Gas Vent

723°K

Filter

Feed Pump

Recycle
Pump

353°K

308°K
298°K
Oxygen

HX

Storage
Tank

Condenser

523°K

HX

Recycle
Tank

366°K

Urine & Flush
Water

Evaporator

348°K

Compressor

HX

NH_3 Oxid.
Reactor

Legend

━━━ Vapor/gas

─── Urine

┈┈┈ Recovered Water

Vapor Phase Catalytic Ammonia Removal Flow Schematic

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URINE PROCESSING

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Thermoelectric Integrated Membrane Evaporation Subsystem	Pretreated Urine/Flush Water Avionics Air	Water to Hygiene Processor Brine, Vent Avionics Air
Vapor Compression Distillation	Pretreated Urine/Flush Water	Water to Hygiene Processor Brine, Vent
Vapor Phase Catalytic Ammonia Removal	Untreated Urine/Flush Water O_2, Cabin Air Liquid Coolant	Water to Potable Processor, Vent Liquid Coolant
Air Evaporation System	Pretreated Urine/Flush Water Liquid Coolant	Water to Hygiene Processor Liquid Coolant Return Air from Separator

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HYGIENE WATER PROCESSING

Ultrafiltration

UF
membrane

Raw waste water feed

First-stage
permeate

Soap and
particulates

Low-molecular-weight
dissolved solids

Reverse Osmosis

Feed

Pump

Pressure
controlling
valve

'Salt'
solution

Pure
water

Product
or permeate

Brine

Semipermeable
membrane
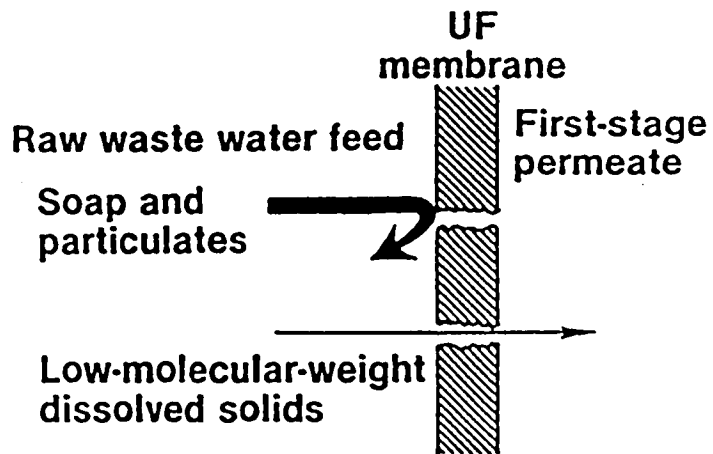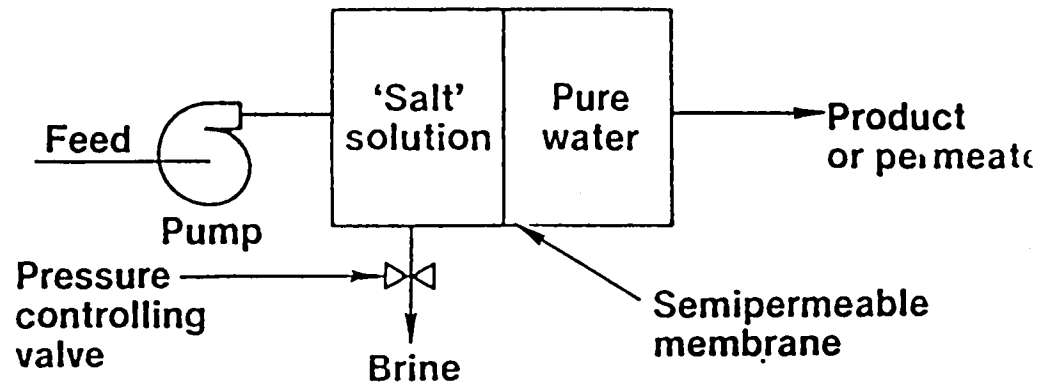
General Operating Characteristics of Ultrafiltration and Reverse Osmosis

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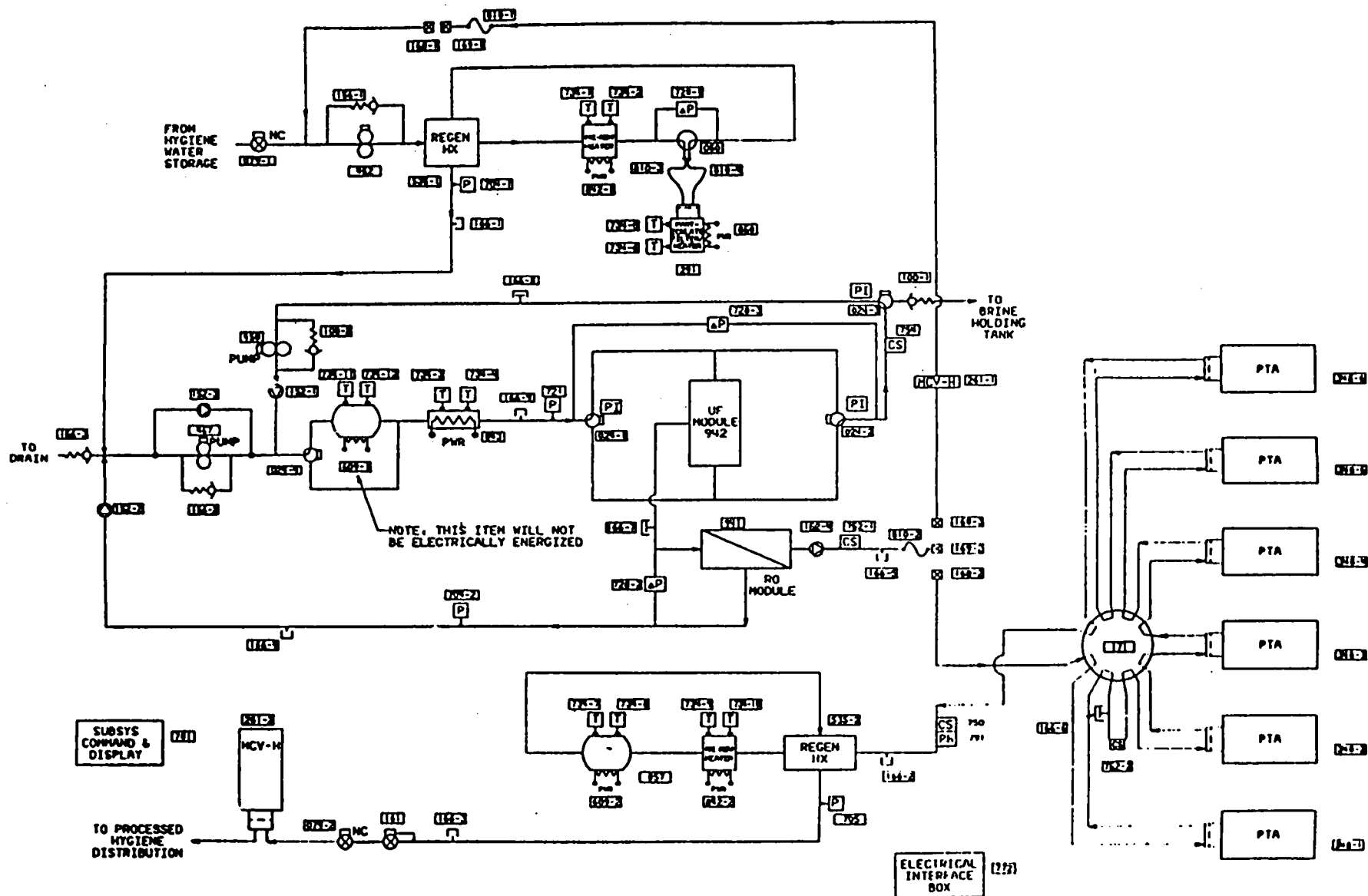
Reverse Osmosis System Schematic for Hygiene Water Recovery

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470

HYGIENE WATER PROCESSING

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Reverse Osmosis	Waste Wash Water/Urine Processor Product Water	Hygiene Water Brine
Multifiltration	See Potable Water Processing	

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POTABLE WATER PROCESSING
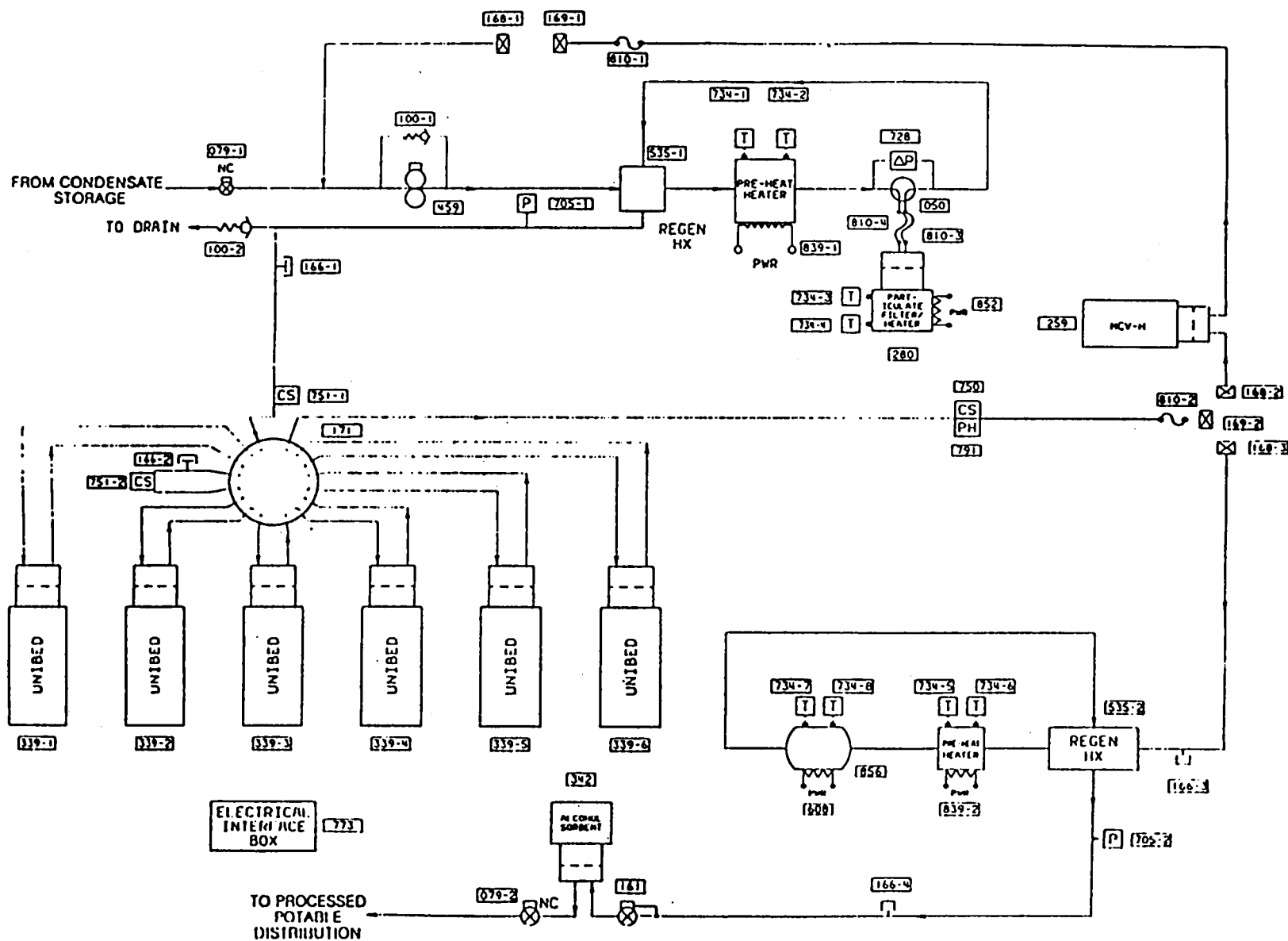
Multifiltration System Schematic for Potable Water Recovery

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474

FEED
Cl⁻   Na⁺

ANION PERMEABLE MEMBRANE

CATION PERMEABLE MEMBRANE

CATION PERMEABLE MEMBRANE

ANION PERMEABLE MEMBRANE

Cl⁻

ANION EXCHANGES

Na⁺

CATION EXCHANGES

(+)

Na⁺

Na⁺

Cl⁻

Cl⁻

OH⁻

OH⁻

H⁺

OH⁻

H⁺

H⁺

OH⁻

(−)

H⁺

CONCENTRATING COMPARTMENT

DILUTING COMPARTMENT

CONCENTRATING COMPARTMENT

CONCENTRATE

PRODUCT

CONCENTRATE
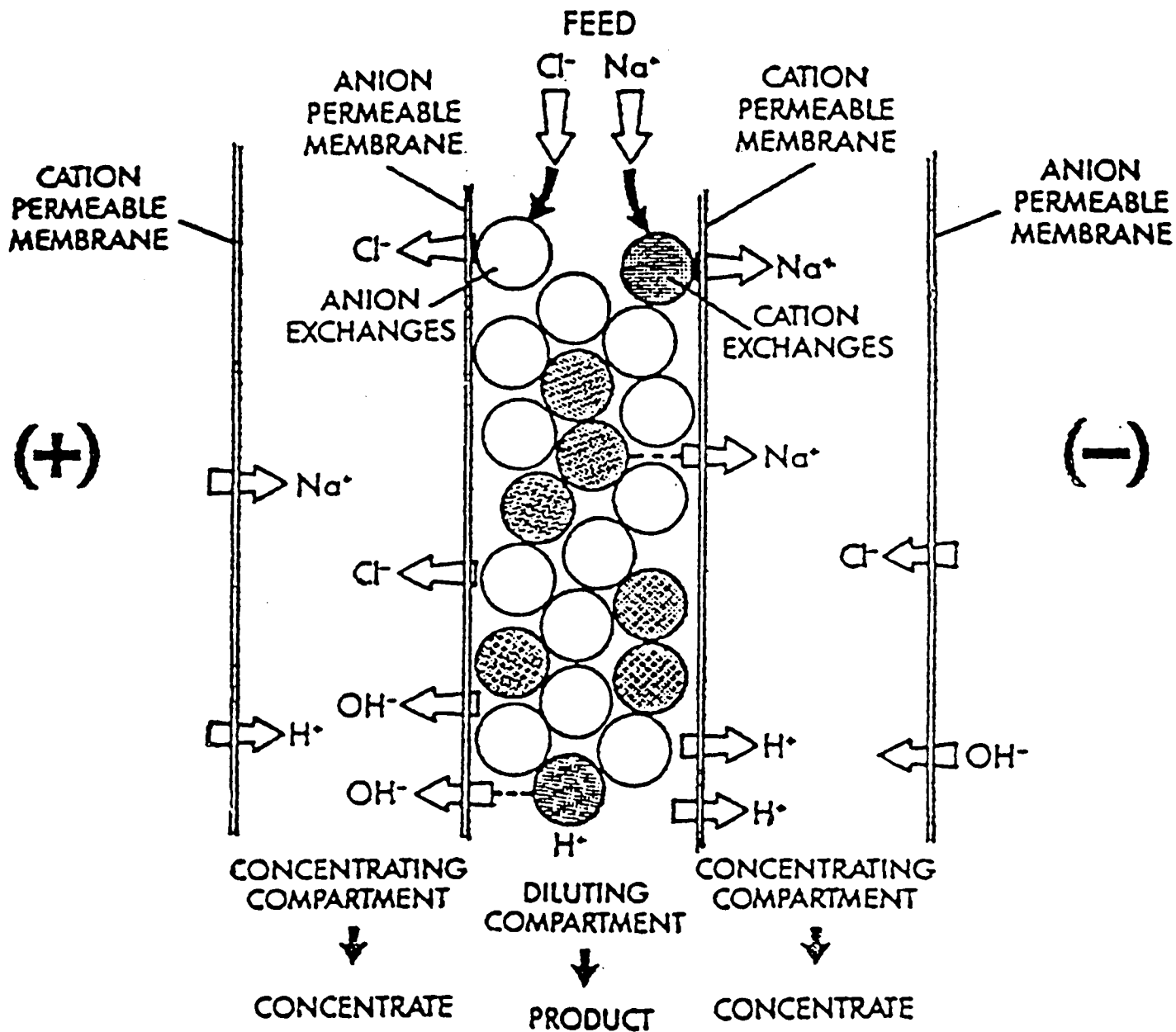
The Electrodeionization Process

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MULTIMEDIA
FILTER

SOFTENER

IONPURE

FEEDWATER

NaCl

NaCl

CARTRIDGE
FILTER

ORGANIC
SCAVENGER
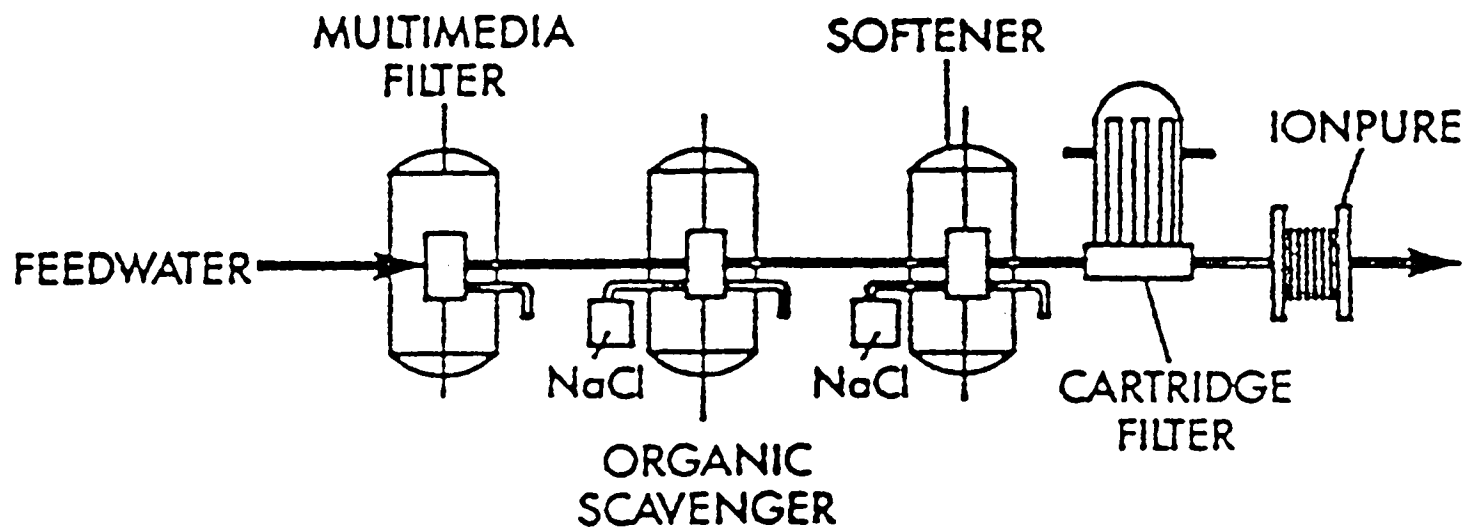
*ASSUMES FEEDWATER SDI$_{15}$ < 4.0 AND FREE Cl$_2$ < 0.2 ppm

Electrodeionization System ("Ionpure") with Pretreatment

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478

POTABLE WATER PROCESSING

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Multifiltration	Condensate from THC/CO_2 Reduction	Potable Water
Reverse Osmosis	See Hygiene Water Processing	
Electrodeionization	Condensate Water from THC/CO_2 Reduction	Potable Water Brine

479

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WASTE MANAGEMENT

FECAL COLLECTION POSITION

COMPACTING POSITION

WASTE COLLECTOR

SEAT

ODOR LID

AIR IN

FECAL COLLECTION BAG

BACTERIA FILTER

LIDS

CANISTER POSITION ACTUATOR

LID DISPENSER ACTUATOR

AIR

WASTE CANISTER

URINE/AIR IN

FLUSH WATER

URINAL

INLET DEBRIS FILTER

ODOR & BACTERIA FILTER

AIR

ODOR & BACTERIA FILTER

URINE & FLUSH WATER

PARTICULATE FILTER

CFE

AIR OUT VENT

AIR OUT

TO THE URINE PROCESSOR

HYGIENE WATER
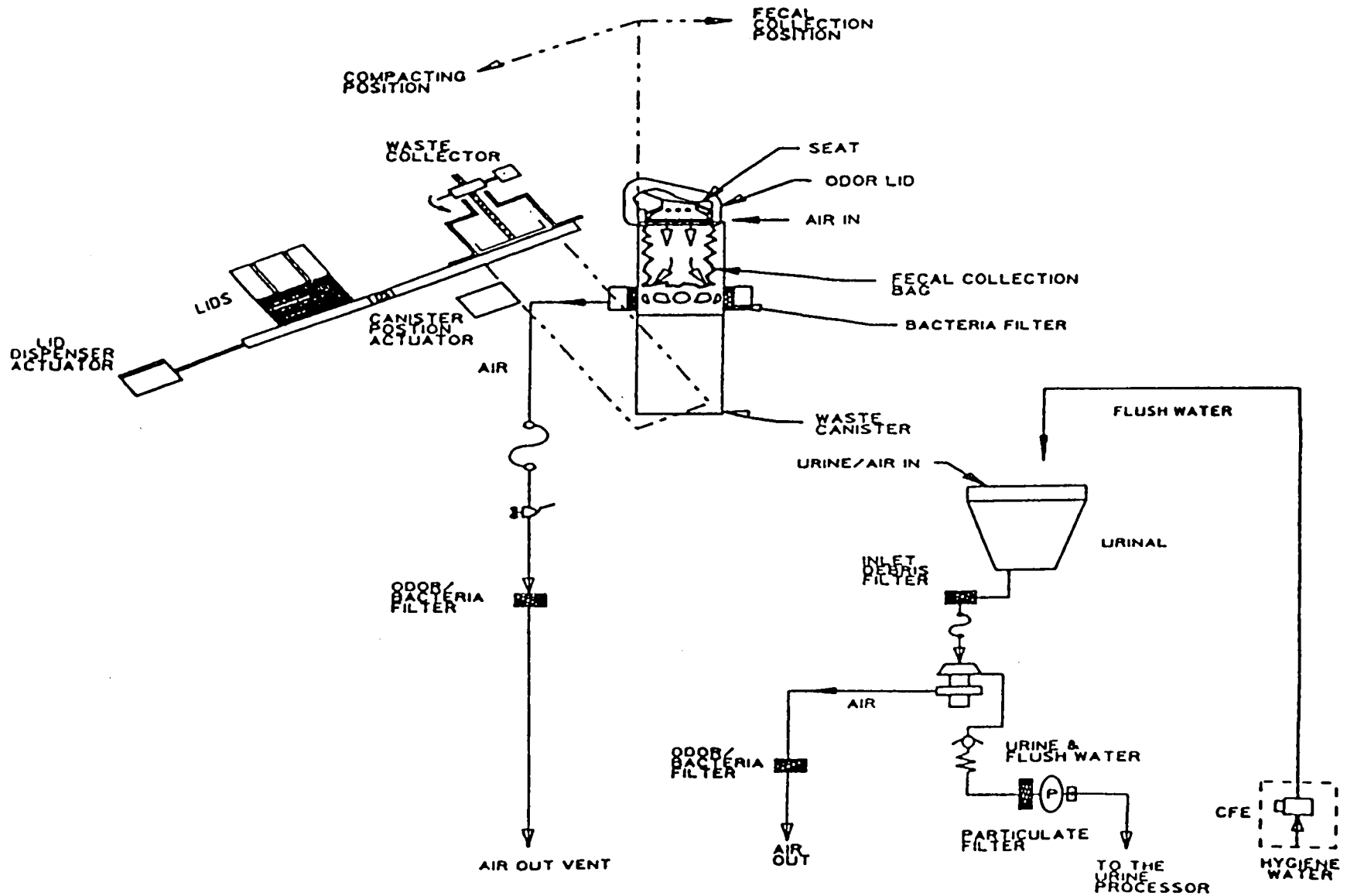
Schematic of the Baselined Urinal/Commode

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N2 PRESSURE

VENT   VENT

WASTES (A)

SOLIDS GRINDER & PUMP

COLLECTING TANK

DISPENSING TANK

LOW PRESSURE PUMP

HEAT EXCHANGER

SOLIDS SEPARATOR

REACTOR

HIGH PRESSURE PUMP

CHECK VALVE

N2 PRESSURE

VENT   VENT

L/G SEPARATOR

N2   CO2   H2

SOLIDS COLLECTION

TANK

CHECK VALVE

COLLECTING H2O

DISPENSING H2O

COMPRESSOR

CABIN AIR (8)

PURIFIED WATER FOR CREW USE

Block Diagram of Supercritical Water Oxidation System

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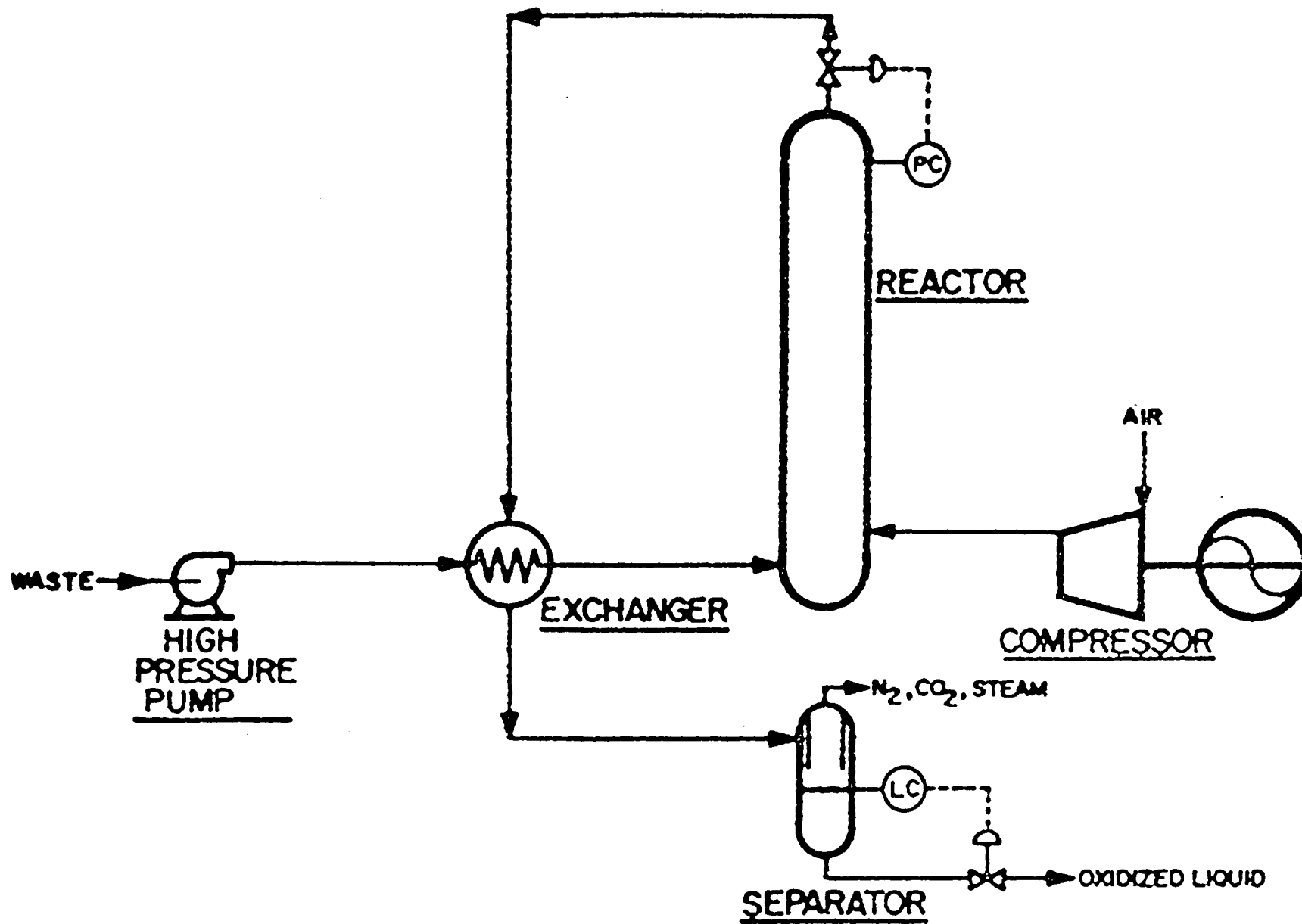
General Wet Oxidation Schematic

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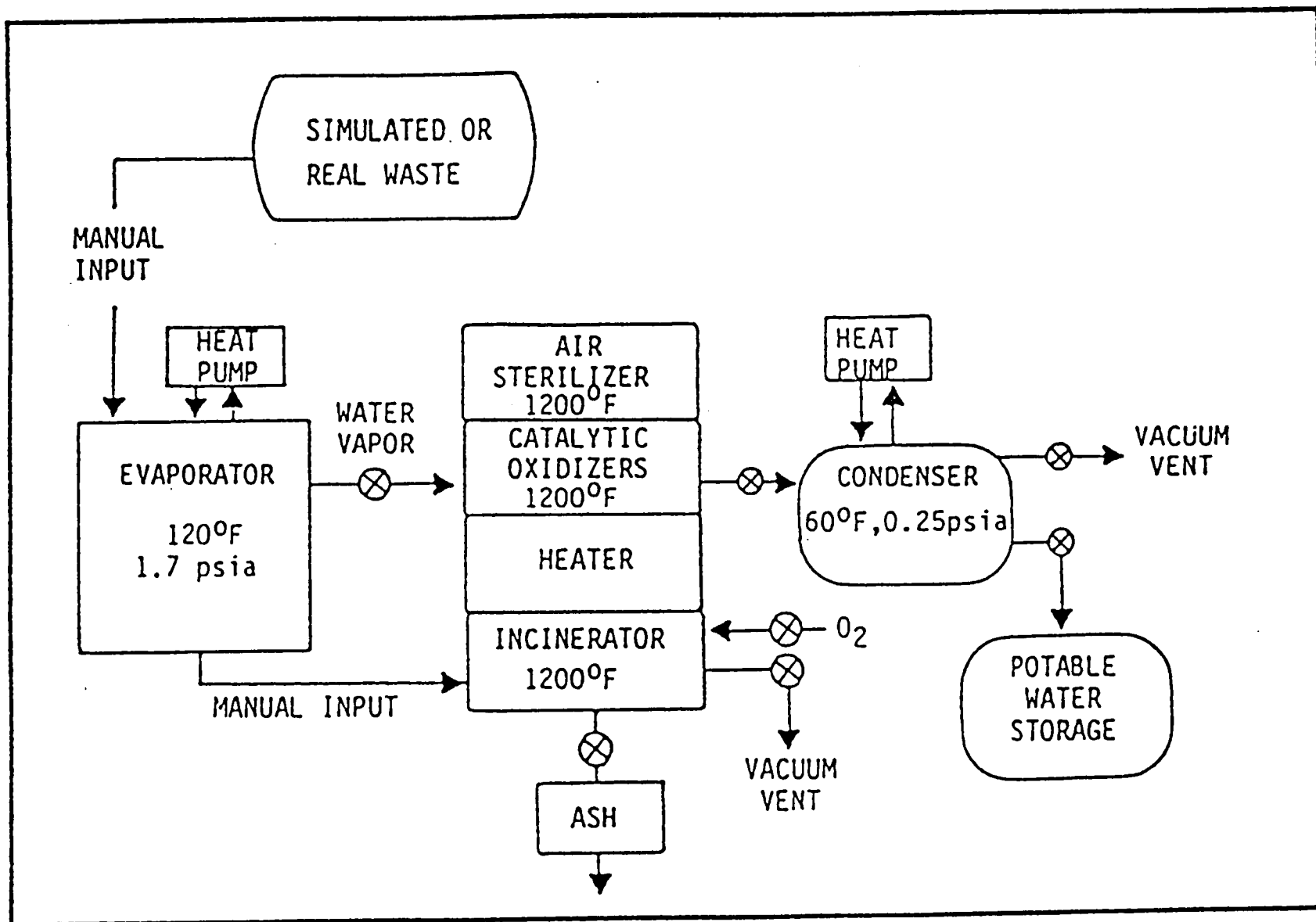
Block Diagram of Waste Managment - Water System

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e^- e^-

CO_2 H_2

Waste Slurry   Strong Acid

General Anodic Reaction   Cathodic Reaction

$C(s) + 2H_2O \longrightarrow CO_2 + 4H^+ + 4e^-$ $4H^+ + 4e^- \longrightarrow 2H_2$
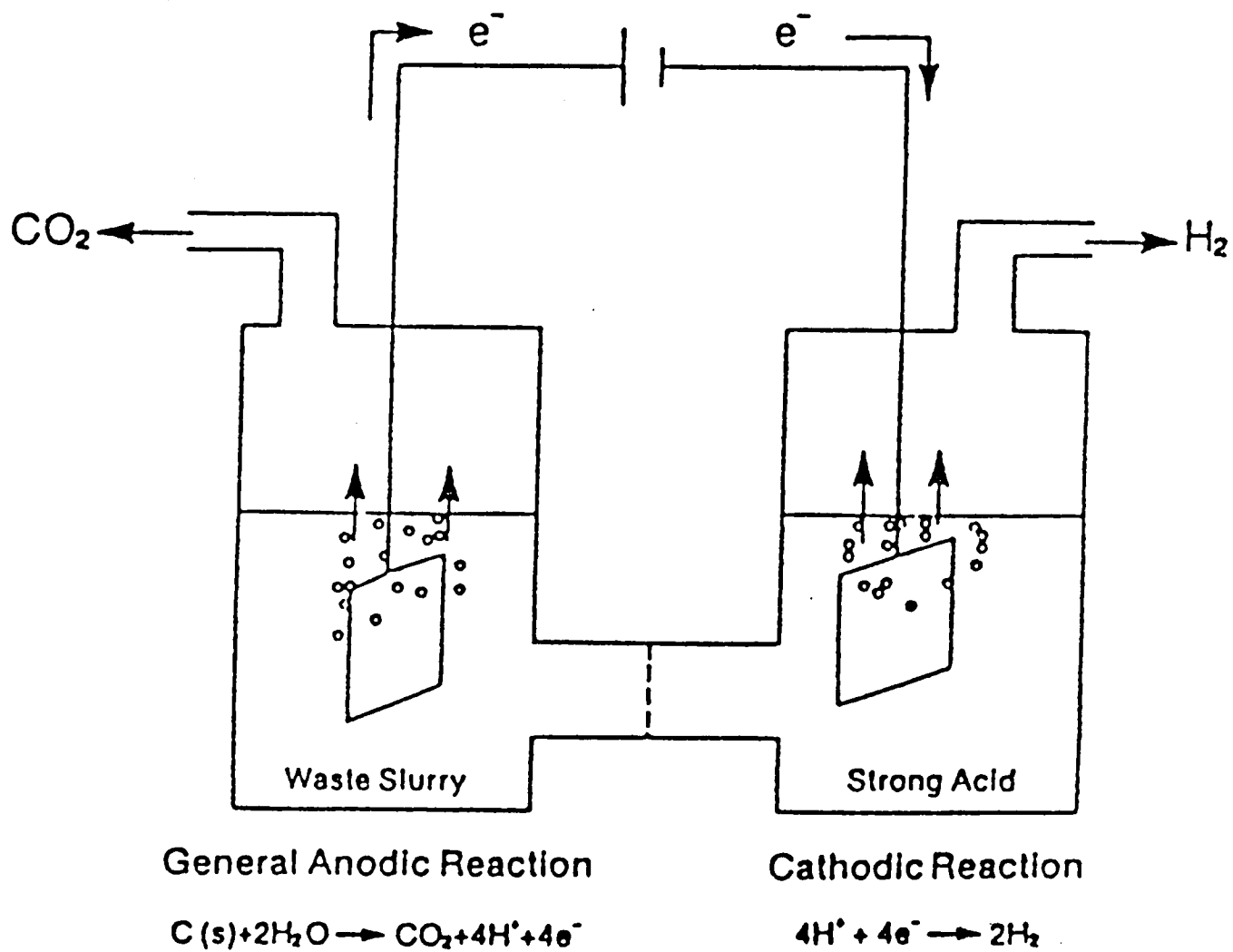
Electrochemical Decomposition Process Schematic

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490
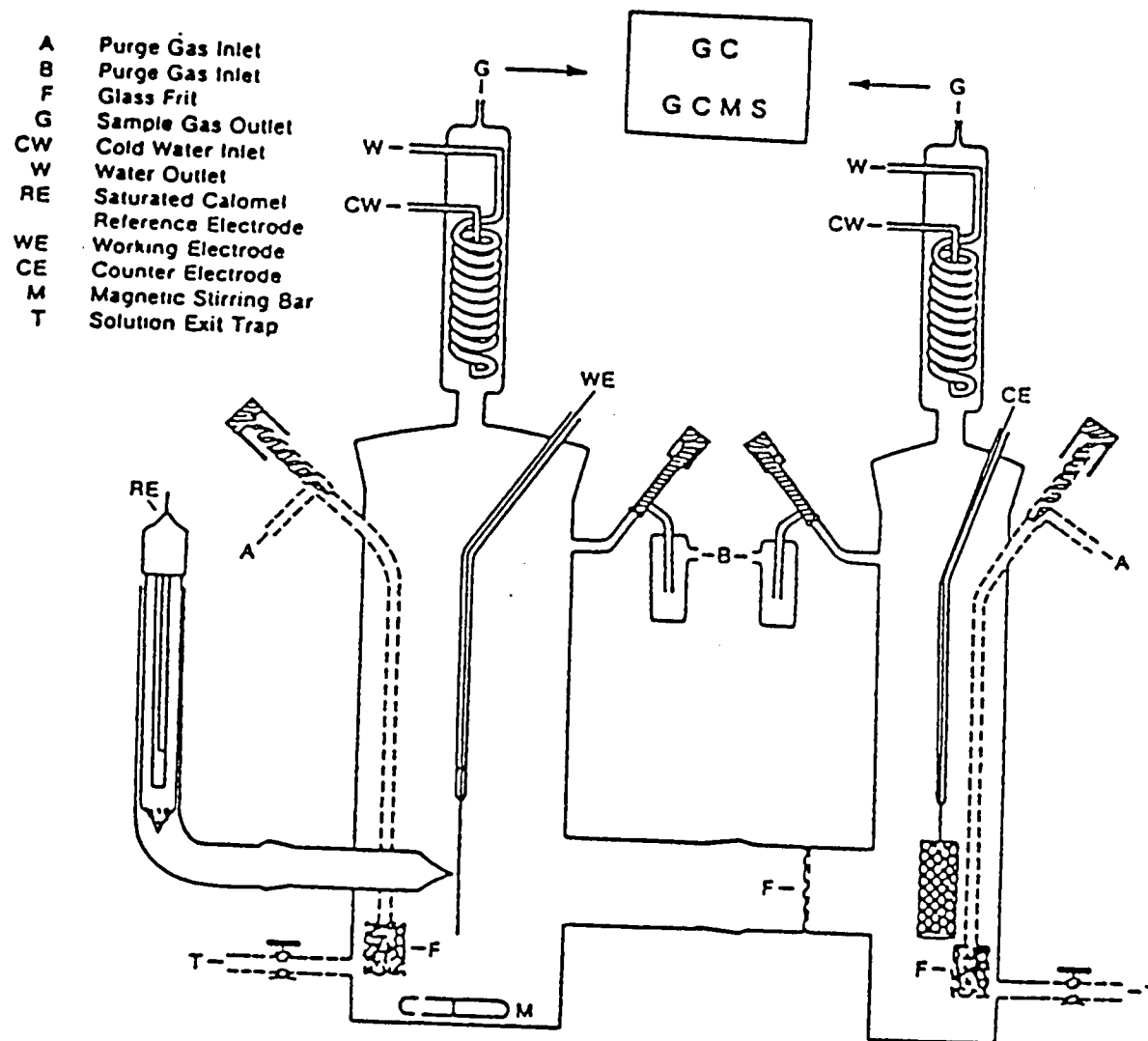
A Diagram of the Electrochemical Decomposition Electrolysis Cell

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WASTE MANAGEMENT

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Storage and Biodegradation	Solid Trash/Human Feces	Return to Earth
Wet Oxidation	Waste Water Solid Waste, O_2	Water and Gases to Posttreatment Solid Waste
Waste Management - Water System	Brine/Rejection Concentrates Air (from urinal)	Return Air Potable Water
Supercritical Water Oxidation	Cabin Air, O_2, Condensate, Wash Water, Urine/Flush Water, Solid Waste, Liquid Coolant	Return Air, Solid Waste H_2, N_2, CO_2 to Storage Potable Water Liquid Coolant Vacuum Vent
Electrochemical Decomposition	New Concept - Interfaces undetermined	

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494

ALTERNATIVE PROCESSES FOR WATER RECLAMATION AND SOLID WASTE PROCESSING IN A PHYSICAL/CHEMICAL-BIOREGENERATIVE LIFE SUPPORT SYSTEM

TOM D. ROGERS
SPACE RESEARCH CENTER
REGENERATIVE CONCEPTS LABORATORY
TEXAS A&M UNIVERSITY

WORKSHOP PRESENTATION
NASA OFFICE OF AERONAUTICS & SPACE TECHNOLOGY
TECHNOLOGY FOR SPACE STATION EVOLUTION
DALLAS, TX
JANUARY 16-19, 1990

N93-27721

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496

Tom D. Rogers
Space Research Center
Texas A&M University

INTRODUCTION

During the past year, increasing attention has been focused on life support systems and the critical role they have in sustaining spaceflight crews. As these explorers undertake missions traveling greater distances from Earth and for longer periods of time, the more critical the need for regenerative life support capabilities.

The selection and development of the present candidate water reclamation technologies has been driven by the same factors requisite for most, if not all, spacecraft systems (i.e., size, weight, volume, power, etc.).

As more studies are conducted toward selection of the Water Reclamation and Management (WRM) system hardware for Initial Operation Configuration (IOC) of Space Station *Freedom,* the primary criteria (weight, volume, power, etc.) appear to have been adequately met. However, information and data found in a number of reports during the past two years indicate that secondary issues (i.e., waste composition, type and level of chemical contaminants and effects of microorganism (primarily bacterial) are significantly affecting the operation and efficiency of the candidate systems. These issues are apparently having a greater impact on system development and evaluation than previously anticipated.

The main objective of this presentation is to focus attention on the emerging influences of these secondary factors and to constructively address these issues by discussing approaches which attack them in a more direct manner. It may be that these secondary issues will equal or surpass the primary factors in guiding the direction of evolutionary technology and design of future water reclamation and waste management/processing systems.

Using these secondary issues as a focal point, two technologies (an old one and a new, emerging technology) are briefly discussed. The technologies can be shown to have substantial merit, but more importantly it is hoped this presentation will stimulate new thinking and approaches toward reducing the impact of the secondary issues as a key element of the evolutionary system research and development. In the long run, it may turn out that these issues may be the most critical of all factors.

Tom D. Rogers
Space Research Center
Texas A&M University

SPACE STATION WATER RECLAMATION AND MANAGEMENT SYSTEM

The Space Station *Freedom* WRM system will have three systems reclaiming water for crew use. At least two of these systems will include backup units. The U.S. Laboratory will have at least two systems and backup units are included in the plans. This is a total of nine units consisting of four different system configurations. Three or four of these systems will likely have daily duty cycles, thus requiring power, monitoring of system function and water quality, consumables and intervehicular activity (IVA) crew time.

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Space Research Center
Texas A&M University
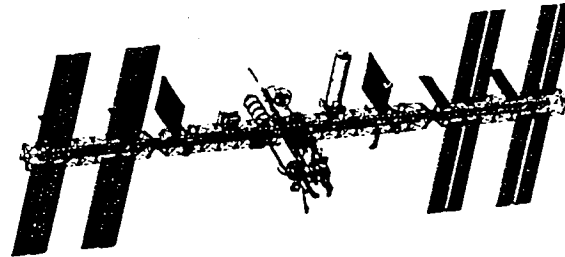
SPACE STATION WATER RECLAMATION AND MANAGEMENT SYSTEM

WRM SUBSYSTEM	WASTE SOURCE	WATER SPECIFICATION
1. CREW POTABLE WATER (PRIMARY) CREW POTABLE WATER (BACKUP)	* Breathing Atmosphere, Humidity Condensate * CO2 Reduction Water	Potable
2. HYGIENE WATER (PRIMARY) HYGIENE WATER (BACKUP)	* Hand/Face Washer, Body Shower * Clothes Washer * Dish Washer	Hygiene
3. URINE PROCESSOR (PRIMARY)	*Urine/Flush Wastewater	Hygiene
4. U.S. LABORATORY-Animal Experiment Facility (Water Recycle System)	* Animal Cage Washer Wastewater	Hygiene
5. U.S. LABORATORY-Ultrapure Water System (UPWS)	* Experiment Waste	Ultrapure

Tom D. Rogers
Space Research Center
Texas A&M University

GENERALIZED DIAGRAM OF WATER RECLAMATION SYSTEMS

An overview diagram applicable to any of the WRM systems in shown in Figure 2. Various combinations of factors and components influence the design of each of the systems. Waste chemical composition, microorganism load and pretreatment regimen influence effectiveness of the primary process which subsequently influences the post-treatment scheme. Microorganism resistance to pretreatment or break-through of the primary reclamation process impacts the entire system and potentially necessitates primary system changeout (in the case of a Reverse Osmosis primary system) or implementation of cleanup procedures of the hardware (VCD or TIMES).

Looking at this situation from another perspective, assume: (1) two or more of the present waste streams could be combined, (2) chemical composition could be more complex, yet less compromising, and (3) the microorganism load and influence is of no concern on the input side with control of microorganisms being the prevention of back-contamination at enduse points. Such an approach would reduce the number of major systems required for primary water reclamation with more attention being focused on post-treatment assemblies to provide the required water quality. Such a step directly addresses effectiveness and efficiency of the entire WRM.

Tom D. Rogers
Space Research Center
Texas A&M University

GENERALIZED DIAGRAM OF WATER RECLAMATION SYSTEMS

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Space Research Center
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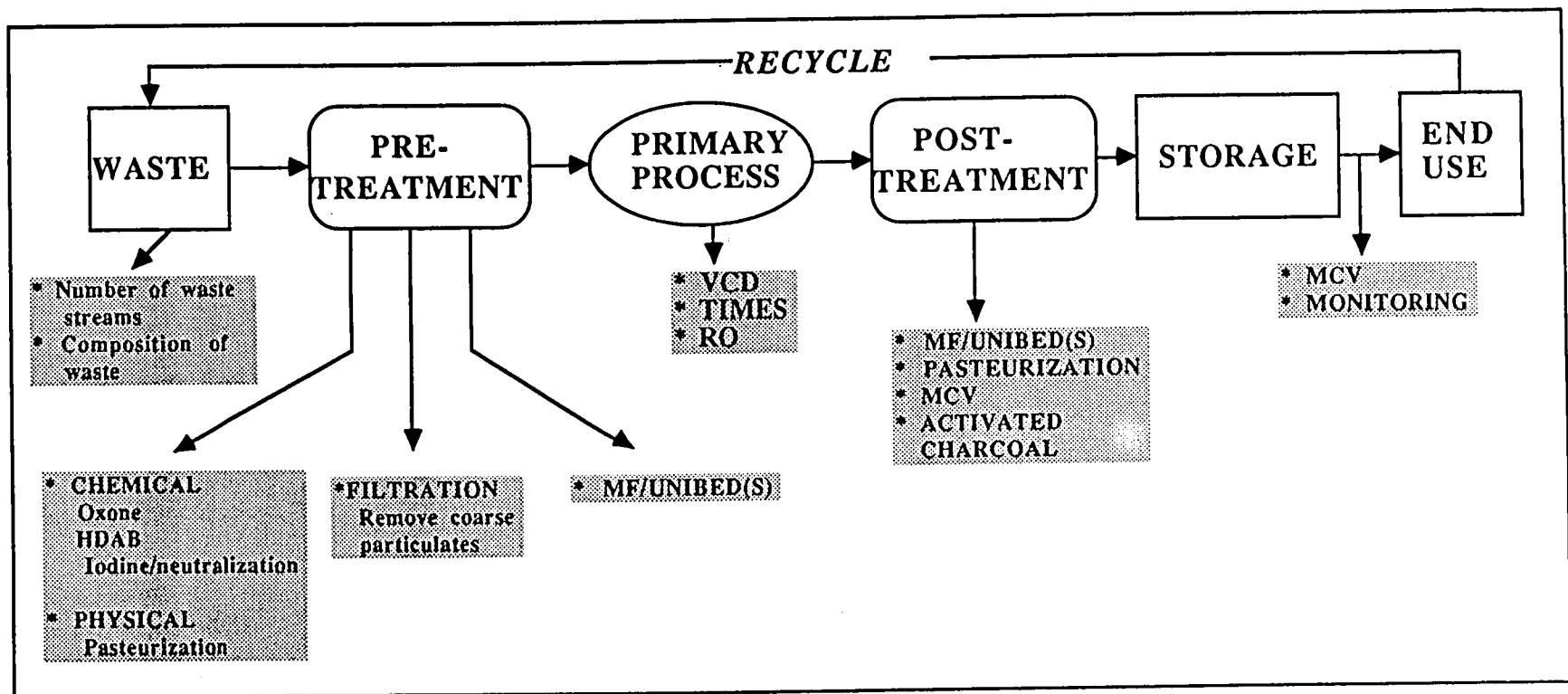
WATER RECLAMATION USING EVAPORATION, CATALYTIC OXIDATION AND CONDENSATION

Using an evaporation, catalytic oxidation and condensation process (referred to earlier as an "old" technology) chemical wastes containing substances known to compromise the present candidate systems, were prepared and processed as shown in Figure 3. The objective was to assess the capability of this process to reduce the total organic carbon (TOC) content to a reasonable level using single-pass treatment. This objective was achieved and the hardware/components were not compromised by the waste stream chemicals.

No attempt was made to investigate the microorganism influence because this aspect was more than adequately investigated and reported by General Electric in studies conducted in the early 1970's. Extensive, periodical microbial monitoring of reclaimed water was conducted during a simulation test lasting more than 180 days. Microorganism presence was not detected in any of the sampling tests as a result of process breakthrough, no did microorganisms have any impact on the process from the influent stream side.

It is pointed out that a variety of pretreatment measures have been employed to reduce the presence and effects of microorganisms of influent waste streams relative to the current technologies, yet little or no attention has been accorded the results of the above studies from nearly two decades ago.

Tom D. Rogers
Space Research Center
Texas A&M University

WATER RECLAMATION USING EVAPORATION-CATALYTIC OXIDATION-CONDENSATION

Tom D. Rogers
Space Research Center
Texas A&M University
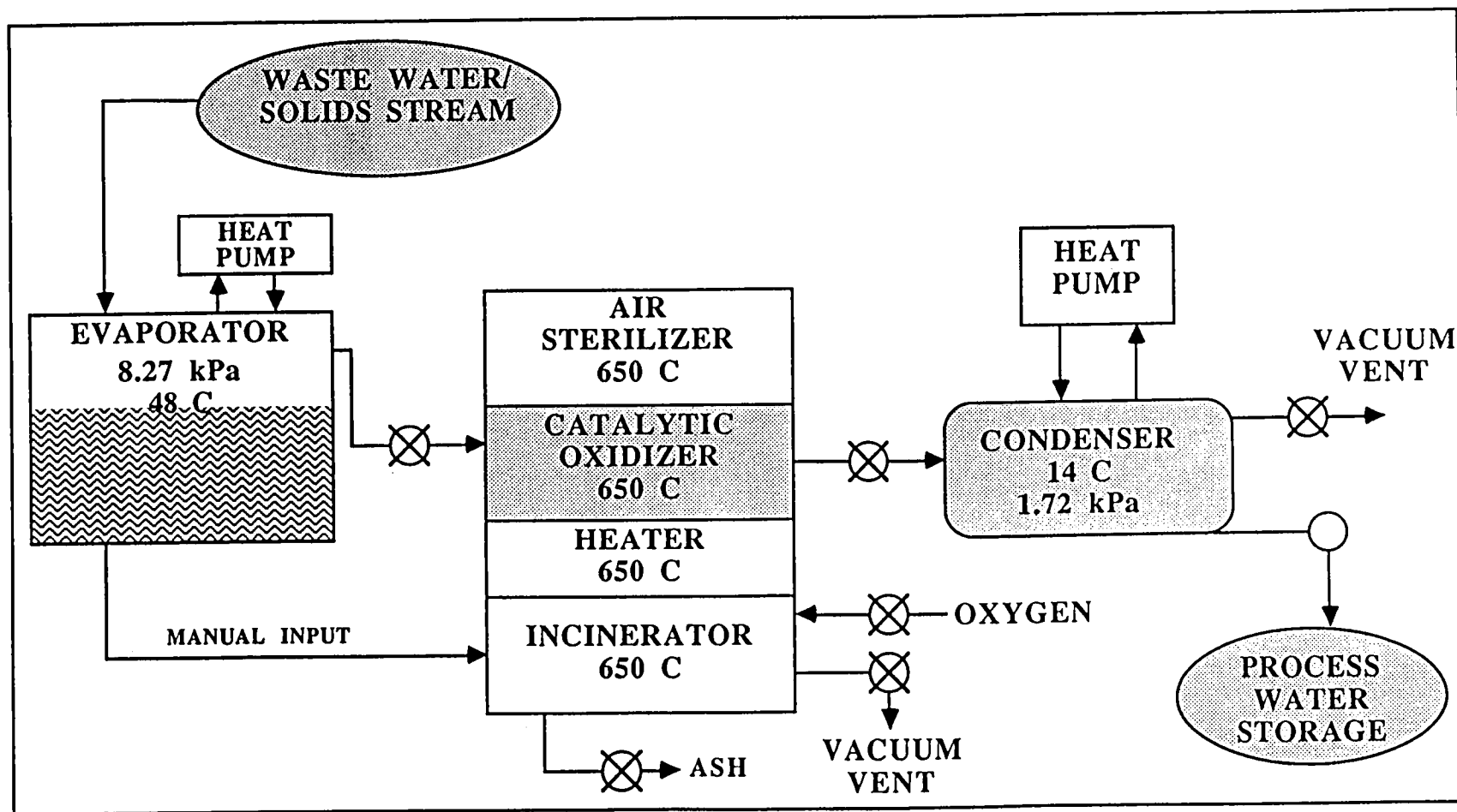
PHASE CHANGE - CATALYTIC OXIDATION - CONDENSATION PROCESSING OF CHEMICAL WASTE WITH HIGH TOTAL ORGANIC CARBON (TOC) CONTENT

Chemical wastes shown in Figure 4 were prepared and processed in the hardware system outlined in Figure 3. The main point of emphasis in the results is that waste having a high TOC was reduced by single-pass processing to a level within, or approaching the TOC specification for hygiene water (10 ppm).

The sodium lauryl sulfate/sodium hydroxide test solution was processed because such chemicals represent an appropriate detergent for use in animal cage washing and a suitable chemical (sodium hydroxide) for removal of biofilm. Single-pass reclaimed water within the specifications for hygiene quality water is a feasible starting point for posttreatment processing to produce both potable and ultrapure water.

Tom D. Rogers
Space Research Center
Texas A&M University

PHASE CHANGE - CATALYTIC OXIDATION - CONDENSATION PROCESSING OF CHEMICAL WASTE WITH HIGH TOTAL ORGANIC CARBON (TOC) CONTENT

CHEMICAL WASTE		PRE- AND POST TREATMENT ANALYSES*					
		SPECIFIC CONDUCTANCE		TOC(mg/l)		AMMONIA NITROGEN(mg/l)	
		PRE-	POST-	PRE-	POST-	PRE-	POST-
Acetic Acid 10 ml/L 2-Propanol 10 ml/L Ammonia Hydroxide 10 ml/L		8890	34	4010	7.5	1050	1.33
Lactic Acid 10 ml/L Methanol 10 ml/L Urea 2 gm/L		1620	123	5632	12	34.2	0.91
Sodium Lauryl Sulfate 10 gm/L Sodium Hydroxide 20 gm/L		70010	143	640	10	1.98	0.06

* Analyses performed by Inter-Mountain Laboratories, College Station, TX.

Tom D. Rogers
Space Research Center
Texas A&M University

MINIMIZING EFFECTS OF MICRO-ORGANISMS AND CHEMICAL CONTAMINANTS IN A WATER RECLAMATION SYSTEM

If a single, front-end approach to waste stream treatment is assumed, and effects of chemical composition and microbial load are minimized or negated, the main focus of the reclamation process then centers on the post-treatment assemblies to provide the appropriate type of end-product water.

Another aspect this process addresses is that of solids/particulates. The influent reservoir (also the evaporator) accumulates solids which can be removed without expending consumables (i.e., filters).Furthermore, there is a potential to concentrate the solids by using latent heat of the oxidation process to dry this material to minimize requirements for mass and volume storage and return logistics. A high percentage of solid waste water content or moisture can be recovered and maintained within the recycle loop.

Through application of advances in engineering technology, materials, instrumentation and catalysts at lower temperature regimens, the energy requirements for operating this 18-year old hardware system can be significantly reduced. At least half of the issues listed in the following table are already known to be substantially resolved by using phase-change - catalytic oxidation - condensation to recover water and concentrate solids of a complex waste stream.

Tom D. Rogers
Space Research Center
Texas A&M University

MINIMIZING EFFECTS OF MICROORGANISM AND CHEMICAL CONTAMINANTS IN A WATER RECLAMATION SYSTEM

WASTE INPUT STREAM
* LIQUID/SOLIDS (CREW/FACILITY)
* SELECTED EXPERIMENT WASTE (USL)

ARS

TCCS

VENT GASES

HYGIENE WATER

STORAGE TANKS

Multifiltration Post-Treatment Assemblies

EVAPORATOR/ SOLIDS RESERVOIR

SOLIDS ACCUMULATION
Storage or Additional Processing

CATALYTIC OXIDIZERS

CONDENSING UNIT

Use latent heat to maintain pasteurization temperature of water in storage tanks

MF/MCV POTABLE WATER

EXPERIMENT WATER
* NON-IODINATED
* PYROGEN-FREE
* STERILE

LEGEND:
MF: Multifiltration
TCCS: Trace Contaminant Control System
ARS: Air Recirculation System
MCV: Microbial Check Valve

Tom D. Rogers
Space Research Center
Texas A&M University

ELECTROCHEMICAL UNIT FOR WATER POST TREATMENT

This process represents a means of treating recovered waste water without the use of chemical expendables and currently is being investigated as a pre and post treatment method. The design is based around the use of a solid polymer electrolyte (SPE) similar to that used in fuel cells. Organic contaminants are removed by oxidation as water is passed over the anode surface.

In feasibility studies, the level of contamination of water containing typical organic contaminants of space craft recovered water was reduced from 50 ppm to 1 ppm and below. Another aspect of this process is that, by utilizing suitable electrolytes, SPE-based electrolysis systems can generate short-lived oxidizing species in the recovered water providing unique post treatment and disinfection capabilities.

ELECTROCHEMICAL UNIT FOR WATER POST TREATMENT

TYPICAL DISSOLVED ORGANIC CONTAMINANTS

Acetic Acid: $CH_3COOH + 2H_2O \longrightarrow 2CO_2 + 4H_2$

Benzoic Acid : $C_6H_5COOH + 12H_2O \longrightarrow 7CO_2 + 15H_2$

Octanoic Acid : $CH_3(CH_2)_6COOH + 14H_2O \longrightarrow 8CO_2 + 22H_2$

Urea: $NH_2CONH_2 + H_2O \longrightarrow CO_2 + N_2 + 3H_2$

ORGANIC OXIDATION REACTIONS

Tom D. Rogers
Space Research Center
Texas A&M University

ELECTROCHEMICAL SOLID WASTE PROCESSING AND WATER RECOVERY

Urine contains high levels of chloride ions. Electrolysis of these wastes produces chlorine at the anode which leads to the buildup of hypochlorite in the waste. Hypochlorite is a powerful disinfectant and particulate solids are dissolved during this treatment. In addition, the treated material is partially purified through the oxidative removal of dissolved organic material. This represents a means of pre-treating urine and solid waste, for recovery of water, without the use of expendables.
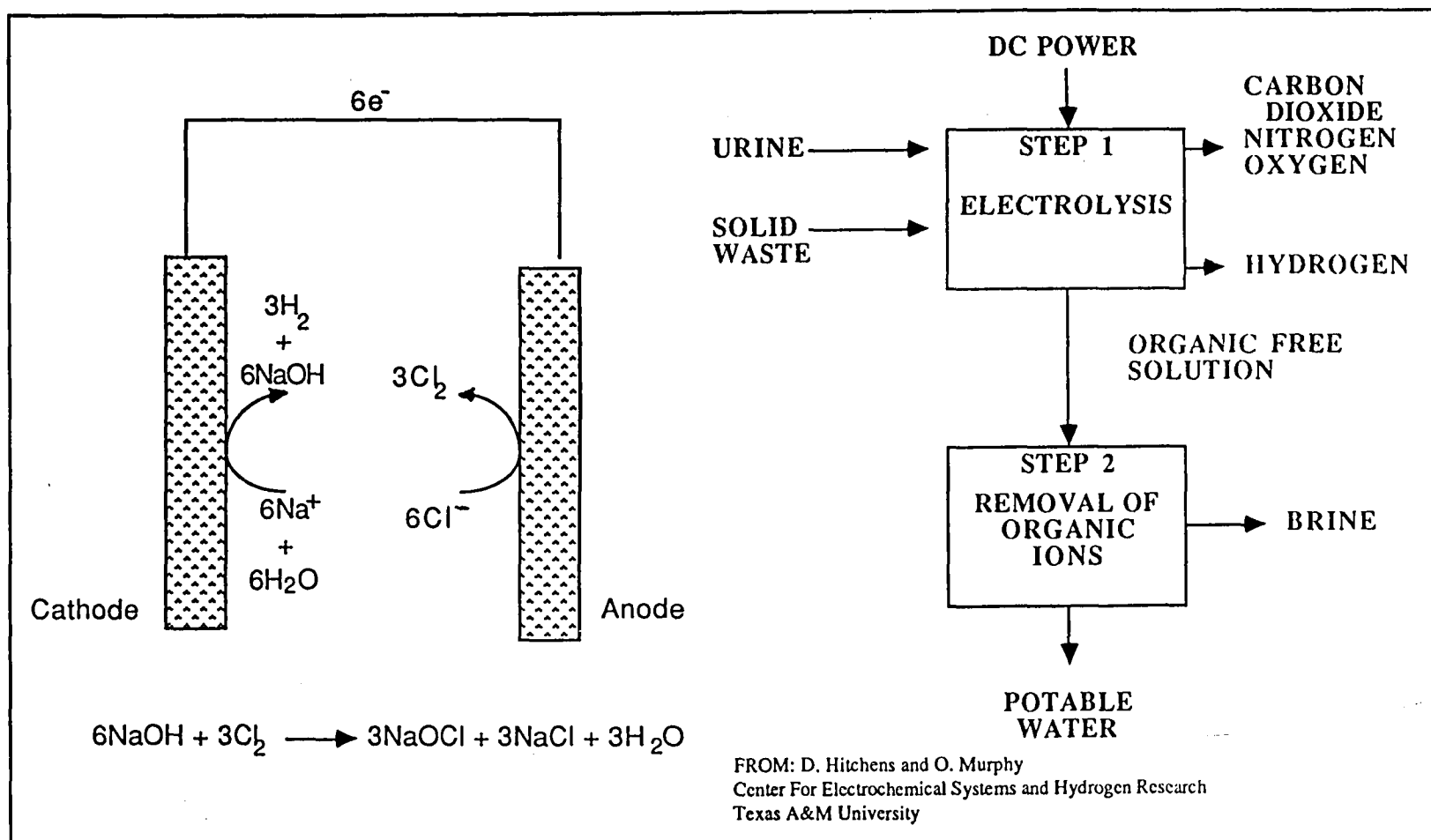
Tom D. Rogers
Space Research Center
Texas A&M University

ELECTROCHEMICAL SOLID WASTE PROCESSING
AND WATER RECOVERY

$$6NaOH + 3Cl_2 \longrightarrow 3NaOCl + 3NaCl + 3H_2O$$

FROM: D. Hitchens and O. Murphy
Center For Electrochemical Systems and Hydrogen Research
Texas A&M University

Tom D. Rogers
Space Research Center
Texas A&M University

ISSUES INFLUENCING EVOLUTIONARY TECHNOLOGY DEVELOPMENT

No reports have been found assessing the impact the factors previously listed (Fig. 6) would have on IOC Space Station *Freedom* once the selected systems are placed in operation. However, it is understood that since actual system selection and final design are not yet established and extensively tested, the full compliment of factors can not be accurately evaluated.

In the past, studies have been conducted to assess the attributes of a primary reclamation process or a trade study performed where several systems were compared to arrive at cost and efficiency estimates for a 10-year life expectancy, at least half of the above factors were not adequately considered or not considered at all.

Tom D. Rogers
Space Research Center
Texas A&M University

ISSUES INFLUENCING EVOLUTIONARY TECHNOLOGY DEVELOPMENT

OBJECTIVE:

WRM Technology Development Must Focus On Reducing The Need For:

* Waste pretreatment procedures

* Number of in-line components or treatment subsystems

* Consumables

* Process residuals (brines/rejection concentrates)

* Monitoring requirements

* Storage requirements

* Resupply and return logistics

* IVA monitoring, maintenance and repair time

Tom D. Rogers
Space Research Center
Texas A&M University

PLANNING FOR EVOLUTIONARY TECHNOLOGY DEVELOPMENT

Figure 7 revisits several excerpts illustrating planned objectives for evolutionary technology direction. The task at hand is to closely assess factors and issues discussed in this report (including issues not mentioned) and use the conclusions to organize and implement the appropriate reserch, development and testing program.

The primary factors (i.e., size, weight, volume, power, etc.) which have influenced the present systems may not be as critical in the future. For example, advances in space power generation, storage and delivery will lessen the impact of this factor. Development of a Lunar Outpost moderates the concern for weight and size, and artificial gravity or lunar gravity negates certain issues relative to microgravity.

Tom D. Rogers
Space Research Center
Texas A&M University

PLANNING FOR EVOLUTIONARY TECHNOLOGY DEVELOPMENT

PLANNING FOR TECHNOLOGY EVOLUTION:

"Water Reclamation: Direct treatment of waste water (urine, wash water, and condensates) by processes not using any expendables to provide potable and hygiene water by reclaiming high content of waste waters by...:"

* "Direct removal of the total water content."
* "Direct removal of the undesirable chemical impurities (organics/inorganics)."
* "Phase-change treatment systems utilizing lunar/Martian gravity or microgravity."

* "Handling and treatment of processed water (post treatment) to remove trace contaminants and bacteria without expendables."

From: Small Business Innovation Research, Section 12.03, Regenerative Life Support: Air, Water and Waste Management. SBIR 89-1, p 81, 1989.

CURRENT STATUS:

The phase-change(evaporation), catalytic oxidation, condensation process discussed in this presentation already meets most, if not all, of these requirements.

The electrochemical system discussed in this presentation is a prime candidate to meet these requirements.

UV-Ozone treatment is also a prime candidate.

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INCREASED FIRE AND TOXIC CONTAMINANT DETECTION RESPONSIVITY BY USE OF DISTRIBUTED, ASPIRATING SENSORS

WALLACE W. YOUNGBLOOD
WYLE LABORATORIES
HUNTSVILLE, ALABAMA

N93-27722

As Space Station Freedom evolves and matures over its lifetime, it is anticipated that there will be a need to enhance its habitable region fire and toxic contaminant responsivity and sensitivity, especially in those regions of low air circulation rates. Such regions may include unpowered equipment racks, storage bins, etc. The use of distributed sensors with centralized detectors is suggested as an efficient means for accomplishing this goal. The use of the concept described herein for Space Station application was suggested by Matt Cole of the NASA Johnson Space Center. The concept has been outlined in Reference 1.

The use of more sensitive detectors and, possibly, detection devices of different types can produce enhanced fire signature information leading to reduced false alarms. The concept described herein is not intended to replace already planned fire detection devices, but is meant to supplement them with increased information.

Reference 1: Youngblood, W.W. and Vedha-Nayagam, M.: Advanced Spacecraft Fire Safety: Proposed Projects and Program Plan. NASA CR 185147, October 1989.

OBJECTIVES:

- ENHANCE FIRE AND TOXIC CONTAMINANT DETECTION RESPONSIVITY IN HABITABLE REGIONS OF SPACE STATION

- REDUCE SYSTEM WEIGHT AND COMPLEXITY THROUGH CENTRALIZED DETECTOR/MONITOR SYSTEMS

- INCREASE FIRE SIGNATURE INFORMATION FROM SELECTED LOCATIONS IN A SPACE STATION MODULE

- REDUCE FALSE ALARMS

The concept of fire detection by means of aspirating flow through long tubes is commonly used in earth-based systems. Fenwal Inc. markets the VESDA (Very Early Smoke Detection Apparatus) fire detection system which draws air through a long tube to a central detector for the early detection of incipient fires in such critical areas as computer rooms (Reference 2). The Brunswick Corporation has developed aspirating flow tube sensors for mining activities such as underground haulageways (Reference 3). Tube lengths in this case measure up to several hundreds of meters. More recently, the Systron/Donner Co. has marketed an aspirating flow smoke detector for use in aircraft cargo bays. This system uses the aircraft ventilation system to induce flow through ionization-type smoke detectors from specific regions of the cargo bay (see accompanying figure).

Reference 2:   Johnson, P.F.: Fire Detection In Computer Facilities. Fire Technology, Volume 22, No. 1, February 1986, pp. 14-32.

Reference 3:   Thomas, E.D.: A Pneumatic Sampling Fire Detection System In An Underground Haulageway. IEEE Transactions, Industrial Applications, Volume IA-19, No. 3, Part 1, May-June 1983, pp. 440-444.

ASPIRATING SMOKE DETECTORS: AIRCRAFT CARGO BAY
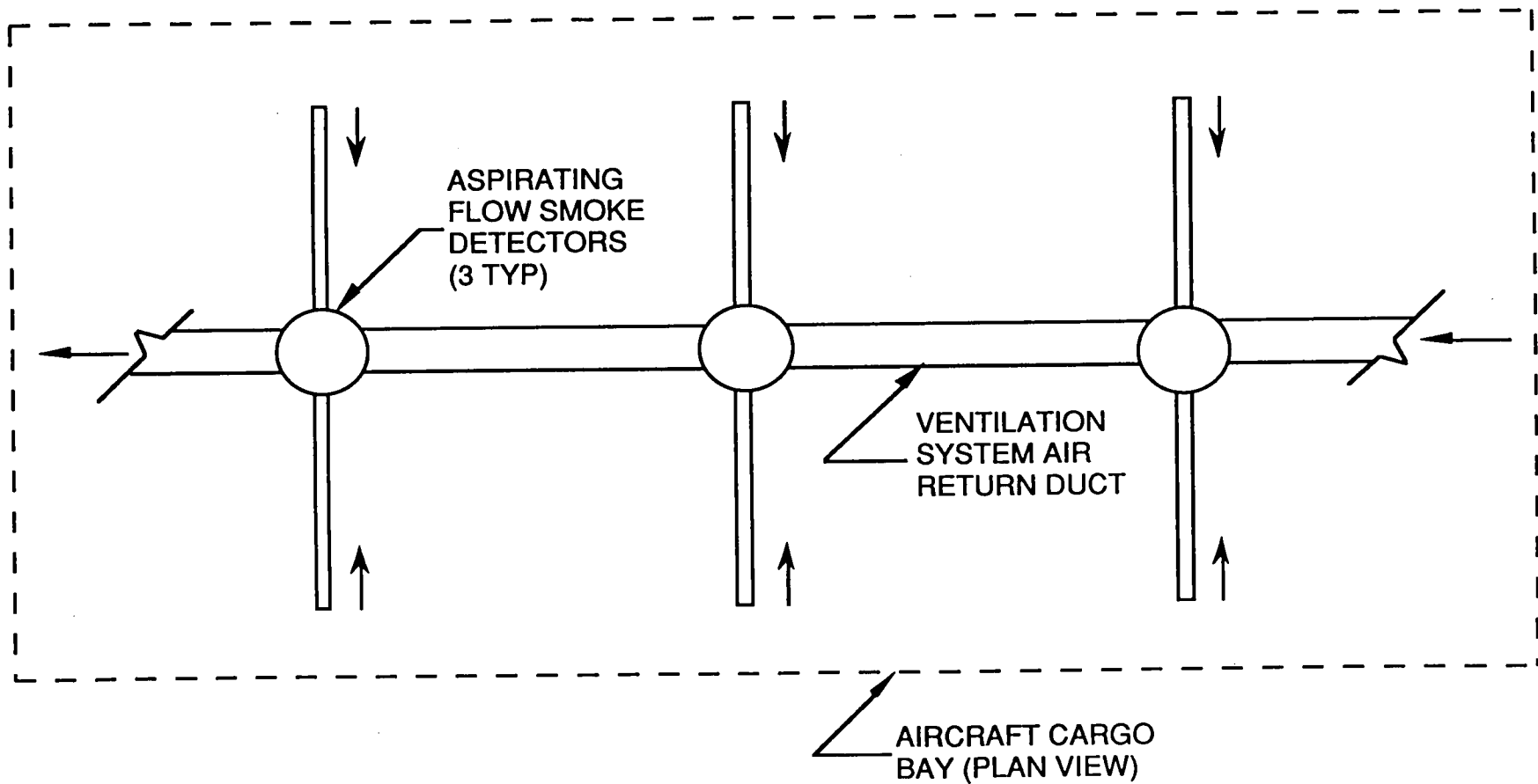
ASPIRATING FLOW SMOKE DETECTORS (3 TYP)

VENTILATION SYSTEM AIR RETURN DUCT

AIRCRAFT CARGO BAY (PLAN VIEW)

521

The schematic of the centralized detector/monitor concept shows a number of distributed sensors (SL(1), SL(2) . . . SL(N)) feeding into a central detector unit via a programmable selection valve. The sensors consist of small diameter tubes through which air from selected locations is induced to flow by means of a fan unit and/or connection to a ventilation system air return duct.

The concept described herein is not intended to replace fire detection devices in powered equipment racks and other potentially hazardous regions. The distributed sensor concept is designed to monitor quiescent regions of spacecraft modules and provide enhanced monitoring of gaseous contamination.

GENERAL SCHEMATIC OF CENTRALIZED DETECTOR/MONITOR CONCEPT
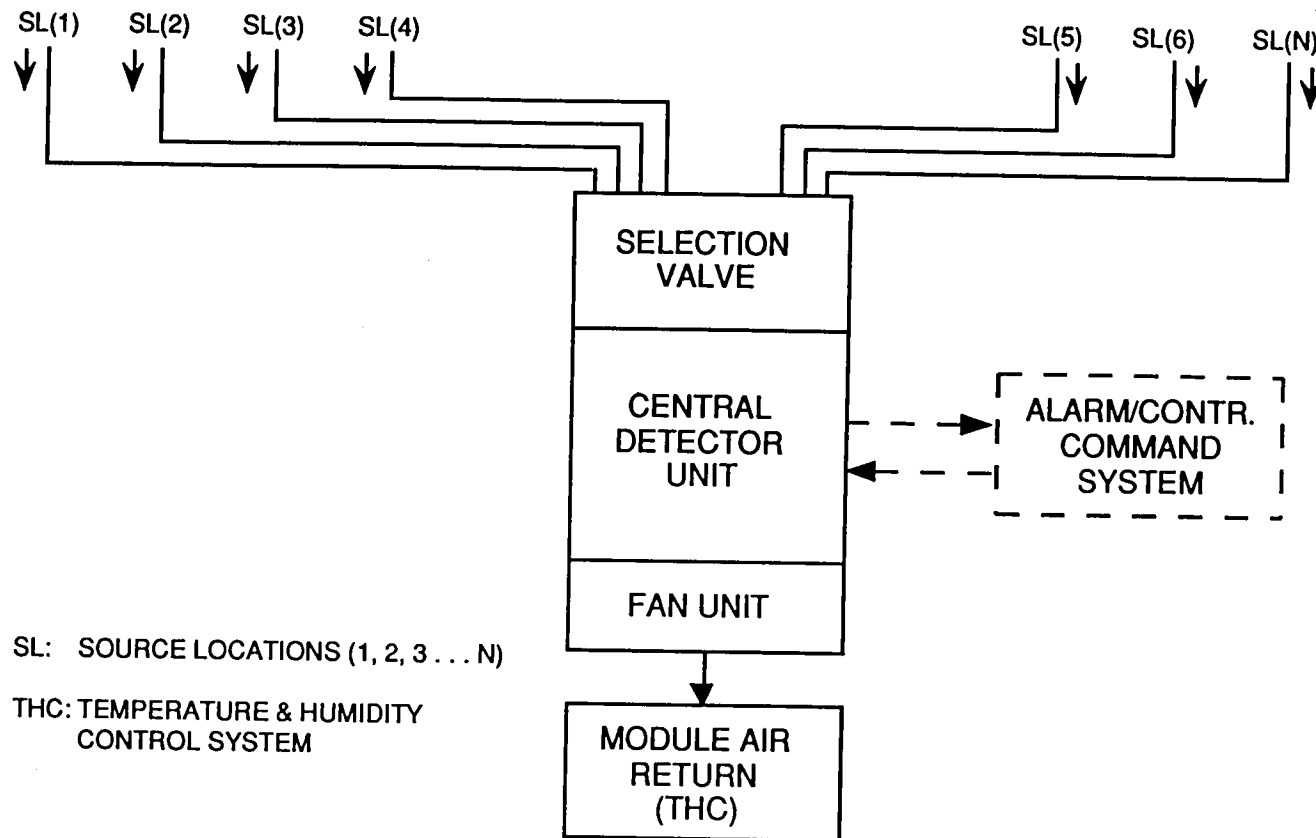
SL(1) SL(2) SL(3) SL(4)   SL(5) SL(6) SL(N)

SELECTION VALVE

CENTRAL DETECTOR UNIT

ALARM/CONTR. COMMAND SYSTEM

FAN UNIT

MODULE AIR RETURN (THC)

SL: SOURCE LOCATIONS (1, 2, 3 . . . N)

THC: TEMPERATURE & HUMIDITY CONTROL SYSTEM

The centralized detector/monitor can include one or more types of fire detectors and/or contamination monitors. Typically, the ionization-type smoke detectors are currently used in pressurized regions of spacecraft and aircraft.

The centralized detector/monitor concept allows the addition of other detector types, i.e., photo-extinction smoke detectors, and specific gas sensors such as those sensitive to CO and CO_2. In addition, the use of the centralized detector as a source for a mass spectrometer (MS) or gas chromatograph/ mass spectrometer (GC/MS) would provide additional fire signature information. Further, the source location of gaseous contamination (especially toxic species) could be more closely determined.

CANDIDATE TYPES OF FIRE/GASEOUS CONTAMINATION DETECTION DEVICES FOR CENTRALIZED MONITORING:

- **SMOKE DETECTORS**

    - IONIZATION

    - PHOTO-EXTINCTION (LIGHT SCATTERING)

    - PARTICLE COUNTERS

- **GAS SENSORS**

    - CO, CO_2, O_2, H_2

    - OTHER

- **GC/MS**

The paper fire signature response, shown opposite (based on UL 217, Test A), is representative of a slowly pyrolyzing process followed by flaming combustion at about 240 seconds in the example. The results shown are from one of several tests on various materials, all of which were intended to illustrate the relative response of different types of fire detectors exposed to different fire scenarios (Reference 4). Also, the test results lend support to the premise that fires may be detected in their early stages by solid state sensor detection of selected smoke gases. In all of the tests related by Reference 4, the standard types of fire detection devices tested (i.e., ionization and light-scattering smoke detectors, UV sensors, and thermal response sensors) lagged in response behind the production and detection of rapid increases in CO and/or CO_2 .

Note that the scale units for the ordinate of the figure shown opposite are as follows: CO_2 (200 ppm/unit), CO (10 ppm/unit), C_xH_y (12 ppm/unit), H_2 (10 ppm/unit).

Reference 4: Pfister, G.: Detection of Smoke Gases By Solid State Sensors -- A Focus on Research Activities. Fire Safety Journal, Volume 6, No. 3., 1983, pp. 165-174.

PAPER FIRE - UL 217, TEST A (OUTBREAK OF FIRE AT ~240 SEC.)
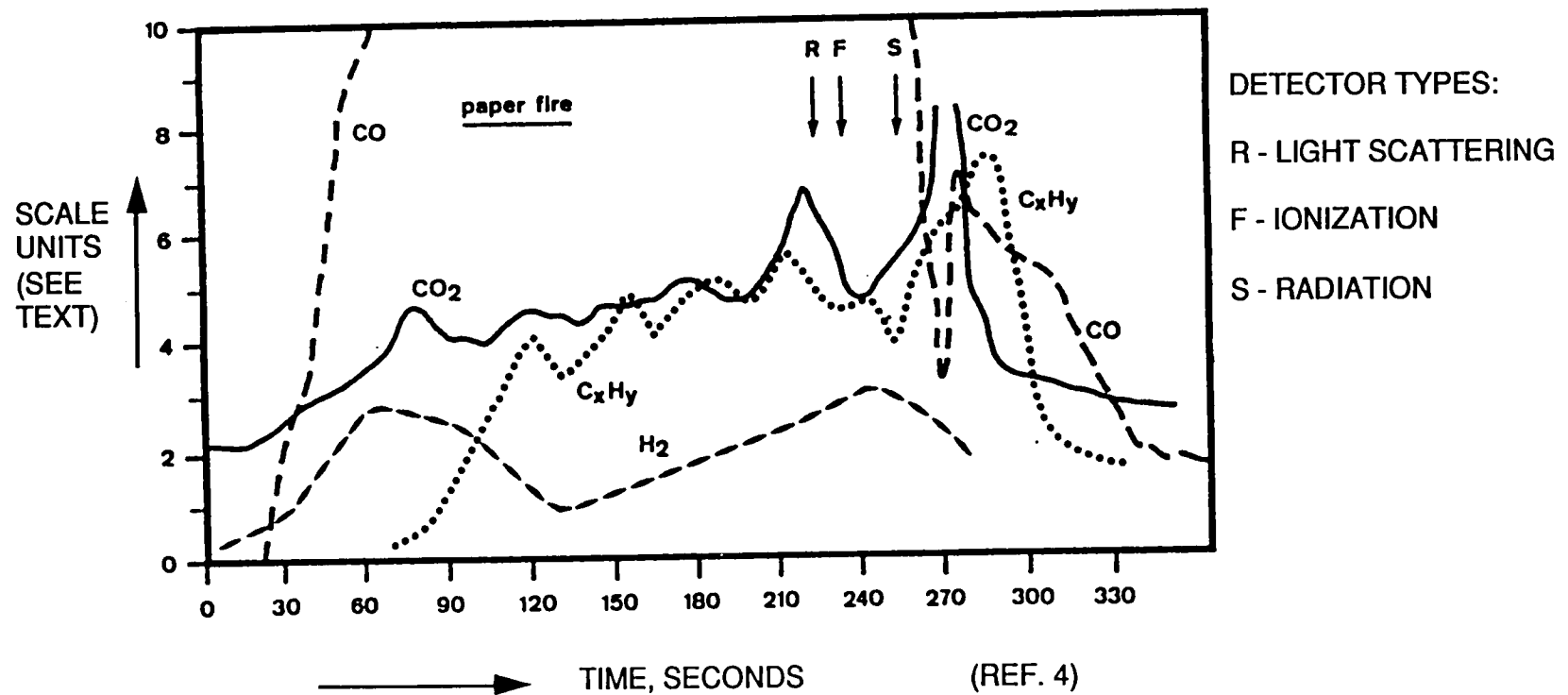
DETECTOR TYPES:

R - LIGHT SCATTERING

F - IONIZATION

S - RADIATION

Standard combustion tests are routinely performed on a wide variety of materials to evaluate the lethality of the gases evolved from the process. The figure shown opposite illustrates the production of CO, HCL and HF from a nonflaming combustion test of a specific wire insulation material. The proprietary results were obtained from a standard NIST test wherein the material was inserted into a preheated oven at 25°C below autoignition temperature and maintained in that environment for 30 minutes.

The results shown are not meant to imply that there are universal and unambiguous fire signatures for all fire scenarios in terms of the gaseous species produced. However, the detected increase in any of a number of gases, i.e., CO, CO_2, H_2, HCL, HF, HCN, etc., can be an independent indication of an unwanted or threatening event. The indicated event could be a gaseous spill or leak, a severe thermal degradation, a smoldering combustion, etc.

NONFLAMING COMBUSTION OF A POLYMERIC WIRE INSULATION

WIRE INSULATION
NIST NONFLAMING TEST
(25°C BELOW AUTOIGNITION)

HF, HCL CONCENTRATION (PPM)

CO CONCENTRATION (PPM)

TIME (MINUTES)

529
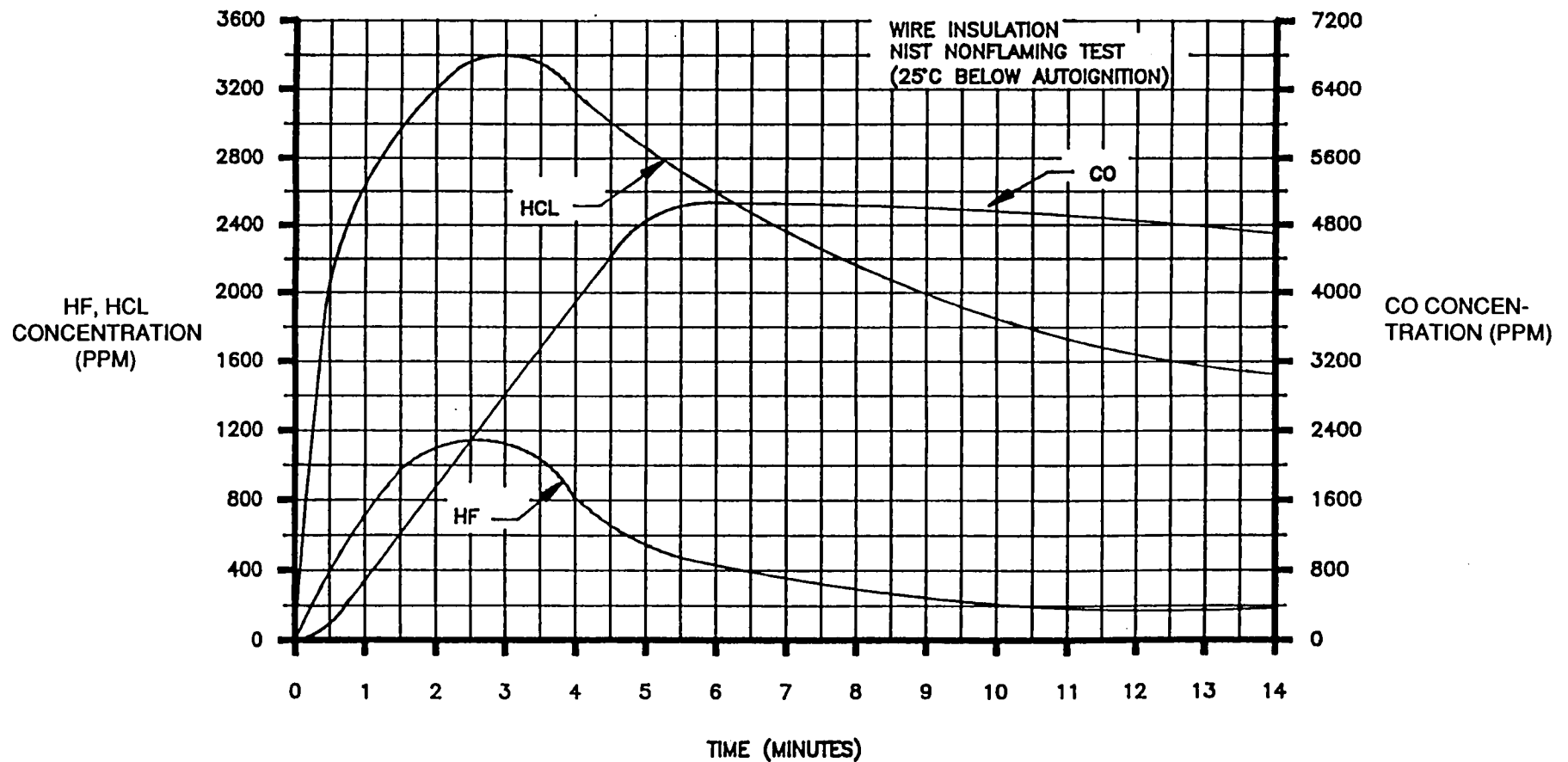
The accompanying figure illustrates the concept wherein multiple sensing tubes are connected to one or more centralized detector/monitor units located in a Space Station module. The sensing tubes may be made of small diameter ($\leq$ 0.64 - 0.95 cm), light-weight materials compatible with all spacecraft safety requirements. Air from the sensing locations is induced to flow to the central unit by means of a fan unit or, alternatively, by connecting the outlet of the unit to the low pressure region of the ECLSS air handling return ducting.

Ideally, no more than one or two central detector/monitor units would be required for each module to supplement the other fire detection and contaminant monitoring devices already planned for Freedom. The time required to sense all of the distributed locations will be determined as a "trade-off" between what is desired and what can be accomplished given the transit times for each sensing tube.

CENTRALIZED SMOKE DETECTORS/MONITORS: SPACE STATION APPLICATION
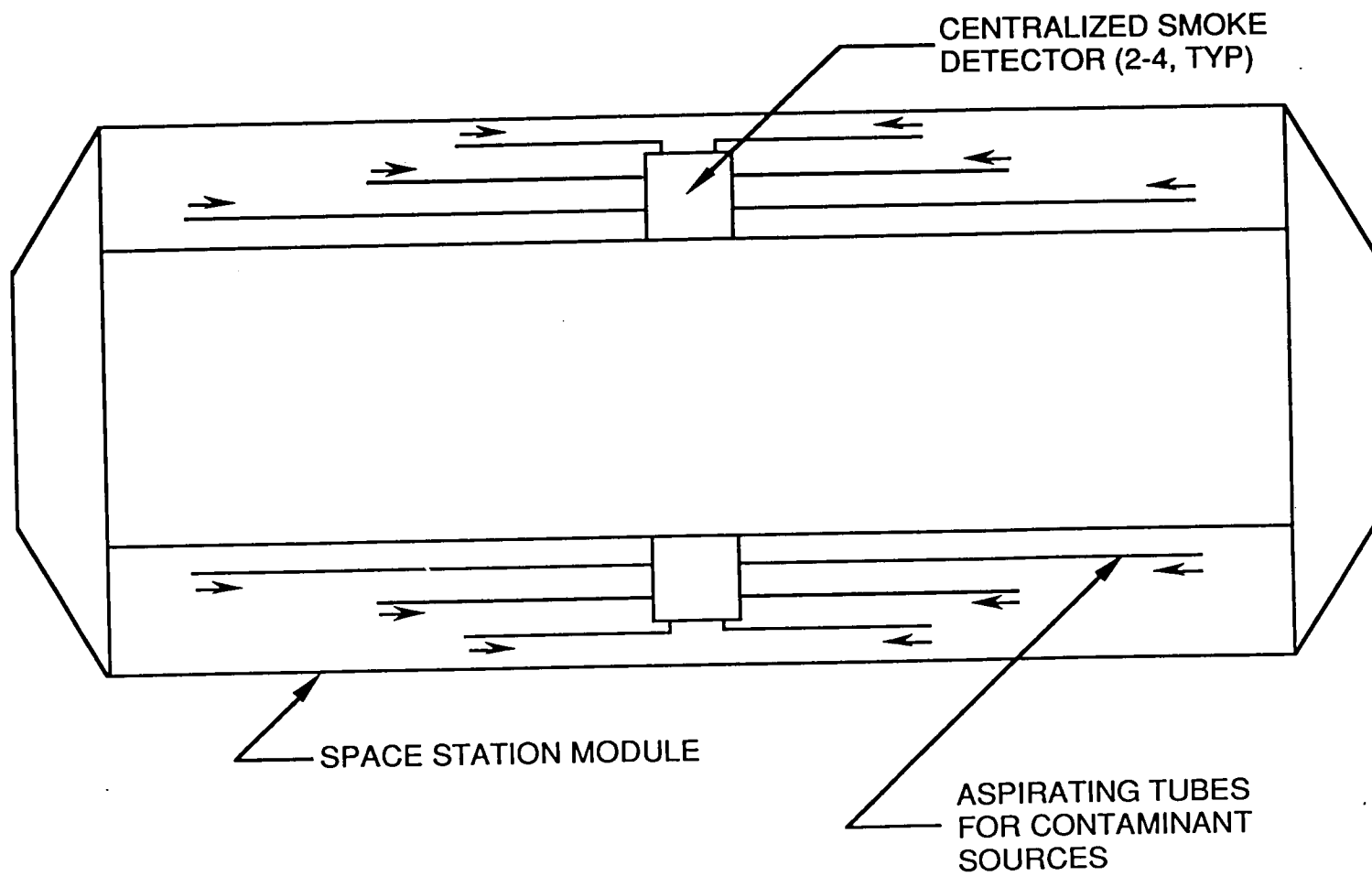
CENTRALIZED SMOKE DETECTOR (2-4, TYP)

SPACE STATION MODULE

ASPIRATING TUBES FOR CONTAMINANT SOURCES

A simplified schematic of a centralized detector/monitor is shown in the figure opposite. Current ground-based systems of this concept typically utilize only the smoke detectors -- usually of the ionization or photo-extinction/light-scattering type. The concept shown in the schematic is somewhat idealized since it assumes the availability of small, solid-state gas detectors sensitive to CO and CO_2.

The inclusion of a mass spectrometer (MS) or gas chromatograph (GC)/MS makes the centralized detector/monitor especially attractive. Most enclosed, habitable spaces on earth do not have, or cannot afford the luxury of a GC/MS. Its inclusion on Space Station Freedom greatly enhances the use of "expert systems" to interpret and communicate the existance of an incipient fire or some other event producing off-nominal aerosols and/or gaseous contaminants.

CANDIDATE DETECTORS FOR INCLUSION IN CENTRALIZED MONITOR

ASPIRATING AIR FLOW FROM
SELECTED SOURCE LOCATIONS
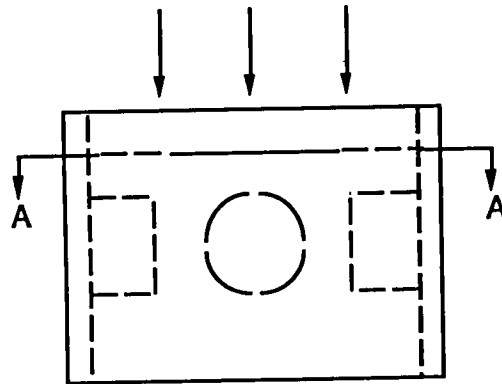
DETECTORS:

• GASEOUS
  - CO_2, CO
  - MS, GC/MS

• SMOKE
  - IONIZATION (ION.)
  - PHOTO-EXTINCTION (PE)

CO DET.

ION. DET.

PE DET

CO_2 DET.

MS GC/MS

ALARM/CONTR. COMMAND SYSTEM

VIEW A-A

534

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SOME PRACTICAL CONCERNS RELEVANT TO USE OF DISTRIBUTED SENSING TUBES:

- RESPONSE (TRANSIT) TIMES MUST BE REASONABLY SHORT

- EXIT SIGNATURES MUST CLOSELY MATCH SENSING REGION CONDITIONS

- SENSING TUBES MUST NOT INTERFERE WITH OTHER SYSTEMS OR OPERATIONS

Some effort has already been expended to determine the transit times for smoke laden air through small diameter tubing (e.g., Reference 5). The induced flow may be either turbulent or laminar depending on the tube diameter and mass flow rate through the tube. For very large pressure drops, the flow may correspond to compressible conditions rather than incompressible as normally assumed for air at low velocities and low pressure drops (i.e., < 100 torr Δ P).

The accompanying figure illustrates some approximate transit times based on relationships derived in Reference 5. For spacecraft applications, it is suggested that transit times of ~ 5-7 seconds may be appropriate.

Reference 5. Hertzberg, M. and Litton, C.D.: Multipoint Detection of Products of Combustion With Tube Bundles. BuMines Report RI 8171, USDI, September 1976.

TYPICAL TRANSIT TIMES FOR AIR THROUGH SMALL DIAMETER TUBING
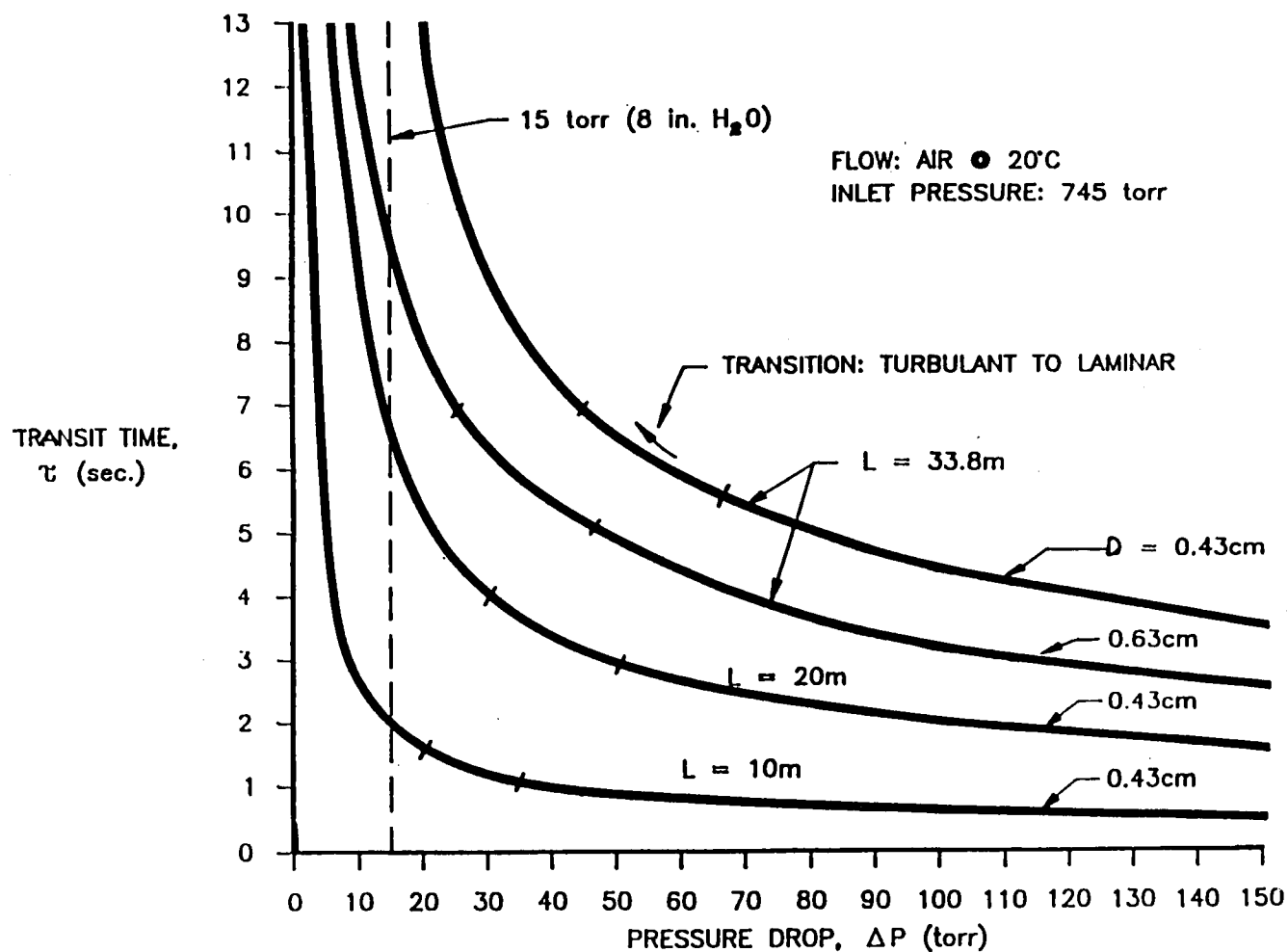
FLOW: AIR @ 20°C
INLET PRESSURE: 745 torr

537

During the transmission of smoke laden air through very long (> 100 m) unheated tubes, some agglomeration and wall condensation will occur with the result that a large percentage of the smallest, submicrometer smoke particles may be "lost." This is especially important to sensing tube systems used in underground mines and haulageways where the tube length may be several hundred meters. This transmission loss is illustrated by the accompanying figure taken from Reference 5 for a tube ID of 0.43 cm.

The short tube lengths anticipated for a spacecraft such as Freedom should pose no significant particle loss problem. However, experimental determination must be undertaken to evaluate both transit times and particle losses for practical spacecraft tube lengths, tube diameters, flow rates, type of smoke, etc.

MEASURED AND PREDICTED SUBMICROMETER PARTICULATE TRANSMISSIONS

TUBE DIAMETER, 0.43 cm

KEY
- ● Aged wood smoke
- ○ Coal smoke
- —— Measured
- —— Predicted for various particle diameters

◄— Turbulent   Laminar —►

PARTICULATE TRANSMISSION, n/n_0

TUBE LENGTH, m   (From Ref. 5)

540

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RECOMMENDATIONS:

1. PERFORM DETAILED ESTIMATES OF SENSING TUBE TRANSIT TIMES AND PARTICULATE LOSSES FOR VARIOUS SENSOR SCENARIOS.

2. REVIEW CURRENTLY AVAILABLE SMOKE DETECTORS AND GAS DETECTORS (e.g., CO_2, CO, H_2) FOR USE WITH THE CENTRALIZED DETECTOR/MONITOR CONCEPT.

3. ASSESS VIABILITY OF GC/MS SMOKE-GAS DETECTION IN THE CENTRALIZED DETECTOR/MONITOR CONCEPT.

4. CONSTRUCT AND TEST A BREADBOARD SYSTEM FOR EVALUATION OF THIS CONCEPT.

5. ESTABLISH SYSTEM OPERATIONAL REQUIREMENTS FOR SPACE STATION FREEDOM USE.

6. ENCOURAGE THE DEVELOPMENT OF VERY SMALL, SOLID-STATE GAS DETECTORS FOR SPACECRAFT USE.

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543

**The ECLSS Advanced Automation Project
Evolution and Technology Assessment**

Presented to:
Technology for Space Station Evolution Workshop
January 17, 1990

Research by:
The Environmental Control and Life Support System
Advanced Automation Project, Transition Definition

Principal Investigator:
    Brandon S. Dewberry
    NASA/MSFC/EB42
    MSFC, AL 35812
    (205) 544-4247
    NASAMAIL: BDEWBERRY

Support:
    James R. Carnes
    Boeing AI Center
    P.O. Box 240002, M/S JA-74
    Huntsville, AL 35824-6402
    (205) 461-2348
    email: ray@huntsai.boeing.com

    Johnson Research Center
    Advanced ECLSS Analysis Team
    Brenda D. Lukefahr   John S. Rogers
    Daniel M. Rochowiak   James W. McKee
    Brian L. Benson
    The University of Alabama in Huntsville
    Huntsville, AL 35899
    (205) 895-6257

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544

The ECLSS AAP Evolution & Technology Assessment

Introduction Description

The Environmental Control and Life Support System (ECLSS) aboard Space Station Freedom will sustain a safe, shirt sleeve environment for its crew and payloads. Development has been divided into six functionally interconnected subsystems: Temperature and Humidity Control (THC), Waste Management (WM), Fire Detection and Suppression (FDS), Atmosphere Control and Supply (ACS), Water Recovery Management (WRM), and Air Revitalization (AR). The last two subsystems, WRM and AR, close air and water environmental loops to an extent never before attempted in space, and will require new technologies which are being extensively tested and analyzed.

The ECLSS Advanced Automation Project

The objective of the ECLSS Advanced Automation Project (ECLSS AAP) is to recommend and develop advanced software for the initial and evolutionary Space Station Freedom ECLS System that will minimize the crew and ground manpower needed for operations. This will be accomplished by first determining which processes may benefit from advanced automation technologies, second, determining the strategies necessary for development and integration of advanced automation systems into the ECLSS project, third, describing the evolutionary path from the baseline ECLSS automation to the more advanced ECLSS automation processes, and fourth, developing advanced automation systems for the ECLSS domain while demonstrating their utility.

The first step, determination of ECLSS processes for
application of advanced automation technologies, is complete.
These processes are outlined in **NASA-MSFC-8-36955-25 ECLSS
Advanced Automation Preliminary Requirements - Final Report**
and in **The ECLSS Advanced Automation Project Phase I Results
presentation to Space Station Transition Definition
Code ST**, the sponsor of this work.

The second and third steps are described in the ECLSS AAP
Project Plan, Management Plan, and Development and Delivery
Plan produced by the Artificial Intelligence Center of Boeing
Computer Services. Knowledge acquisition and engineering are
currently underway in response to the fourth objective.

The ECLSS AAP Evolution & Technology Assessment

Introduction

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                        _____
                       |           |
                       |   ECLSS   |
                       |_____|
                             |
      _____|_____
    _|_        _|_        _|_        _|_        _|_        _|_
   |   |      |   |      |   |      |   |      |   |      |   |
   |THC|      |WRM|      |FDS|      |ACS|      | AR|      | WM|
   |___|      |___|      |___|      |___|      |___|      |___|
               _|_____    __|_____
             _|_        _|_        _|_    _|_     _|_        _|_
            |   |      |   |      |   |  | CO2 | | CO2 |    |   |
            |UPA|      |HWR|      |PWR|  | REM | | RED |    |O2G|
            |___|      |___|      |___|  |_____| |_____|    |___|
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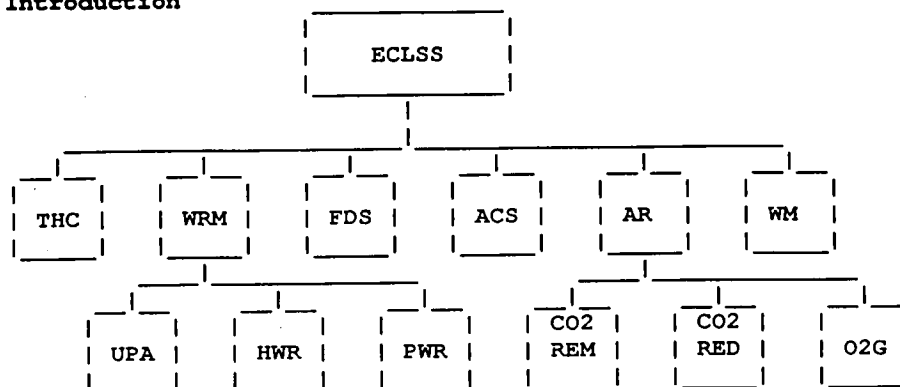
* The ECLSS Advanced Automation Project (ECLSS AAP)

   * Objective: Automation of the Evolutionary ECLSS

   * Approach:
    1) determine applicable processes
    2) determine development and implementation strategies
    3) describe ECLSS evolution from baseline to advanced
    4) develop systems and demonstrate their utility.

   * Status:
    1 - completed in phase I - ECLSS Analysis
        Documented:
        MSFC-8-36955-25 ECLSS Advanced Automation
        Preliminary Requirements - Final Report
        The ECLSS Advanced Automation Project Phase I
        Results presentation to Space Station Transition
        Definition Code ST, the sponsor of this work.
    2&3- completed but in flux
        Documentated:
        The ECLSS AAP Project Plan, Management Plan, and
        Development and Delivery Plan produced by the
        Artificial Intelligence Center of Boeing Computer
        Services.
    4 - In process
        Knowledge acquisition and engineering development
        currently underway.

Introduction Description (continued)

The ECLSS AAP Analysis Overview

Preliminary study indicates the baselined ECLSS is an advanced, flexible, and autonomous system in many areas. Other areas were found in which increased automation should be built in or scarred in its hardware and software systems for evolution. The analysis was performed by both chemical and software experts in order to produce a total ECLSS automation and technology assessment, and applications of advanced software to ECLSS subsystems are emphasized.

Analysis Results

The three research and development areas most apparent in the analysis are autonomous fault detection and isolation of ECLSS processes and subassemblies, advanced chemical and microbial fluid inspection, verifiable closed loop modelling of chemical and microbial recombination in the regenerative processes.

The names applied to these development areas are:

1) Automatic Fault Diagnosis of ECLSS Subsystems,

2) In-line, Realtime Chemical and Microbial Fluid Analysis, and

3) Object-oriented, Distributed Chemical and Microbial Modelling of Regenerative Environmental Control Systems

These technology topics are discussed individually below, giving a description of the technology including the rational behind its endeavor, and possible approaches to development.

Introduction (continued)

* ECLSS AAP Phase I Analysis Overview

  * The ECLSS is an advanced, flexible, and autonomous system in many areas.

  * Deficiencies in
       FDIR,
       Fluid Analysis Instrumentation, and
       Modelling.

  * Hooks and Scars in the baseline system are suggested to incorporate these technologies in the evolution of the ECLSS.

* Analysis Results

  1) Automatic Fault Diagnosis of ECLSS Subsystems,

  2) In-line, Realtime Chemical and Microbial Fluid Analysis, and

  3) Object-oriented, Distributed Chemical and Microbial Modelling of Regenerative Environmental Control Systems

1) Automatic Fault Diagnosis of ECLSS Subsystems Description

Description

The ECLSS Software Architecture contains ground based and flight computer software which monitors and diagnoses faults both inside and across subsystems. In the Space Station software environment, these processes can be developed extensively and used on the ground, and migrated to an on-board processor.

The automatic diagnosis software is developed in the ECLSS ground support center. At a sufficient stage (when there is enough computer resource available) the software is migrating on-board, detecting and isolating faults in the process control assemblies of the ECLSS, and recommending recovery action to the crew.

The ECLSS process control environment is extremely applicable, because of its long latency periods, to automatic fault diagnosis and prediction. ECLSS ground support engineers (and computer programs) have a relatively long time to think about faults in the system.
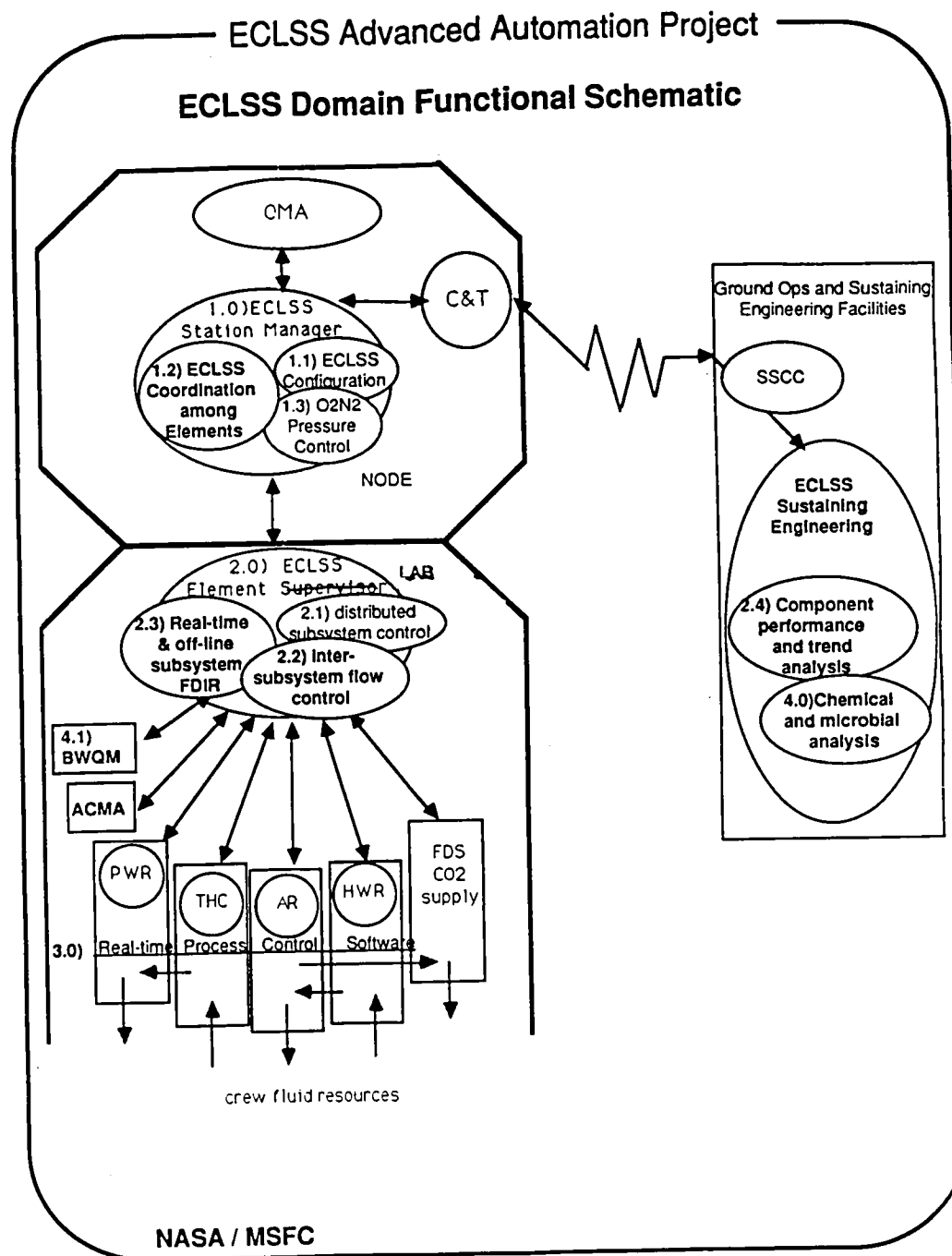
ECLSS Advanced Automation Project

ECLSS Domain Functional Schematic

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1) Automatic Fault Diagnosis of ECLSS Subsystems Description (continued)

Approach

The ECLSS Advanced Automation Project is currently developing Model Based Reasoning (MBR) software for automatic diagnosis of the ECLSS Potable Water Recovery, Hygiene Water Recovery, and Air Revitalization Subsystems.

Knowledge aquistion for automatic Failure Modes and Effects Analysis (FMEA) will provide failure detection, while MBR will provide the diagnosis and prediction functions.

Design Knowledge of the Space Station ECLS system will be stored using automatic Knowledge Aquisition tools. This knowledge will be useful in augmenting the evolutionary ECLSS and for future environmental control system projects.

The ECLSS Advanced Automation Team is software automation oriented, therefor the applications we chose to automate were software-only or mostly software. But our analysis covered system and process advances, which will need to be addressed for a fully automated ECLSS.

1) Automatic Fault Diagnosis of ECLSS Subsystems

* <u>Approach</u>

  * Model Based Reasoning (MBR) Diagnosis

  * Automatic Failure Modes and Effects Analysis (FMEA)

  * Design Knowledge Aquisition for Evolutionary ECLSS and future projects

  * Software-only oriented advancements, but in analysis system and process advances were found to be necessary in order to completely automate the flight ECLSS.

2) In-line, Real-time Chemical and Microbial Fluid Analysis Description

Description

In-line: an automatic part of the fluid recovery loops.

Real-time: constituent data available in seconds.

Provides a running count of a) major Chemical constituents and levels and b) major Microbial constituent levels wherever this smart instrument is hooked into the closed loop fluid system.

This is a difficult but interesting problem that will probably be solved in time to help Space Station ECLSS Evolution, Lunar base, and Mars Mission regenerative environmental control systems.

More complete knowledge of the transitions and interactions which take place in regenerative environmental control systems is necessary to increase the state-of-the-art. Advancements in instrumentation such as this will enhance our analysis and modelling capabilities.

An environmental control system with this degree of regeneration has never been flown before, and the Space Station ECLSS instrumentation must support acquisition of complete fluid constituent data in order to build more robust and autonomous systems in the future.

2) In-line, Real-time Chemical and Microbial Fluid Analysis

* Description

  * In-line: an automatic part of the fluid recovery loops.

  * Real-time: constituent data available in seconds.

  * Running count of
    a) major Chemical constituents and levels
    b) major Microbial constituent levels

  * More smarts in the inline water quality monitor needed to use Space Station Freedom as a testbed for space-based regenerative ECLS systems.

2) In-line, Real-time Chemical and Microbial Fluid Analysis Description (continued)

Approach

There are three or more implementation possibilities, all involving research in both hardware and software:

i) Batch Water Quality Monitor Automation
    Advanced Mass spectroscopy combined with visual frame microscopic data. Knowledge based systems and/or neural networks may analyze the combined patterns resulting in constituent types and levels.
    On the baseline ECLSS, Batch mass spec data along with visual analysis is used by a water quality expert to determine the contents of the water.
    This seems like the proper place to start in order to use the components and processes currently in the baseline ECLSS.

ECLSS Advanced Automation Project

Batch Water Quality Monitor Automation

Baselined BWQM Technique

2.0) ECLSS
Element Supervisor

Manually sampled

4.1)
BWQM
(Mass
Spectrometer)

molecular
mass

BWQM Data

Onboard &
Ground
Analysis

PWR   HWR

raw
potable
water

product
potable
water

raw
hygiene
water

product
hygiene
water
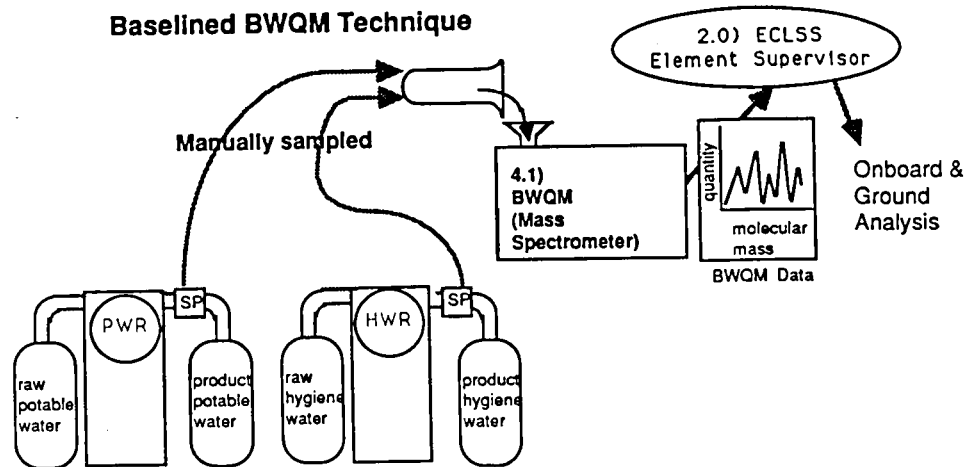
Automated BWQM Technique
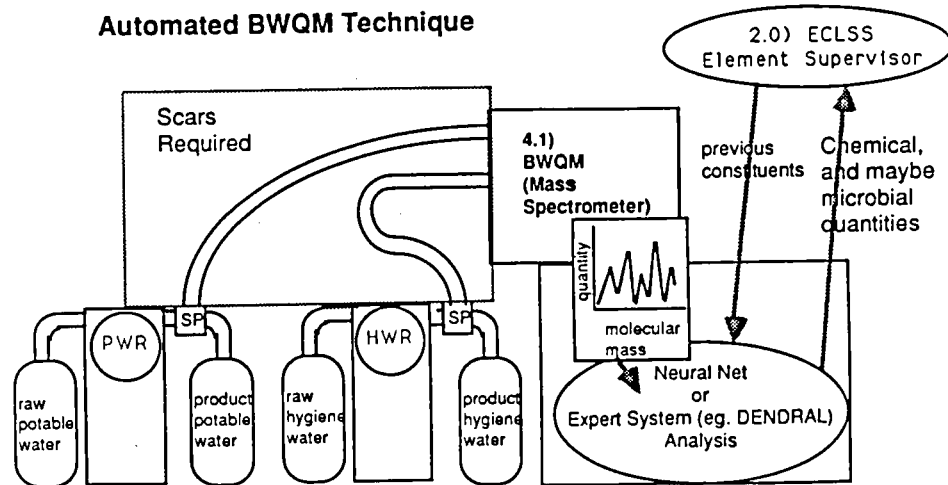
2.0) ECLSS
Element Supervisor

Scars
Required

4.1)
BWQM
(Mass
Spectrometer)

previous
constituents

Chemical,
and maybe
microbial
quantities

molecular
mass

PWR   HWR

raw
potable
water

product
potable
water

raw
hygiene
water

product
hygiene
water

Neural Net
or
Expert System (eg. DENDRAL)
Analysis

NASA / MSFC

2) **In-line, Real-time Chemical and Microbial Fluid Analysis Description (continued)**

Approachs (continued)

ii)   Flow cytometry analysis with neural network analysis
of resulting data is promising candidate technology.
Flow cytometry is the process of determining the size and
shape of a microbe by the deflections of a lazer through
it. Neural networks may be 'trained' to automatically
identify up to two dozen microbe types.
There has been promising results from this
combination of technologies at MIT in their analysis
of sea water.

iii) Enhancements in medical process fluid analysis
technologies. Catch-all approach implying that the
promising medical technologies emerge daily. This void
in automation technology should be filled within the next
10 years and the Freedom Station should be properly
prepared to upgrade.

2) **In-line, Real-time Chemical and Microbial Fluid Analysis (continued)**

* Approachs

    ii)   Flow cytometry analysis with neural network analysis of resulting data.

    iii) Enhancements in medical process fluid analysis technologies.

3) Object-oriented, Distributed Chemical and Microbial Modelling of Regenerative Environmental Control Systems Description

Description

Each process in the ECLSS can be thought of as a semi-independent agent with inputs, processing, and outputs.

Independent enhancement of each subsystem may produce undesired or unknown effects on another subsystem or the stability of the entire ECLSS.

A lab is needed in which models and actual assemblies can be integrated, analized, verified, and upgraded with new information due to Space Station ECLSS results.
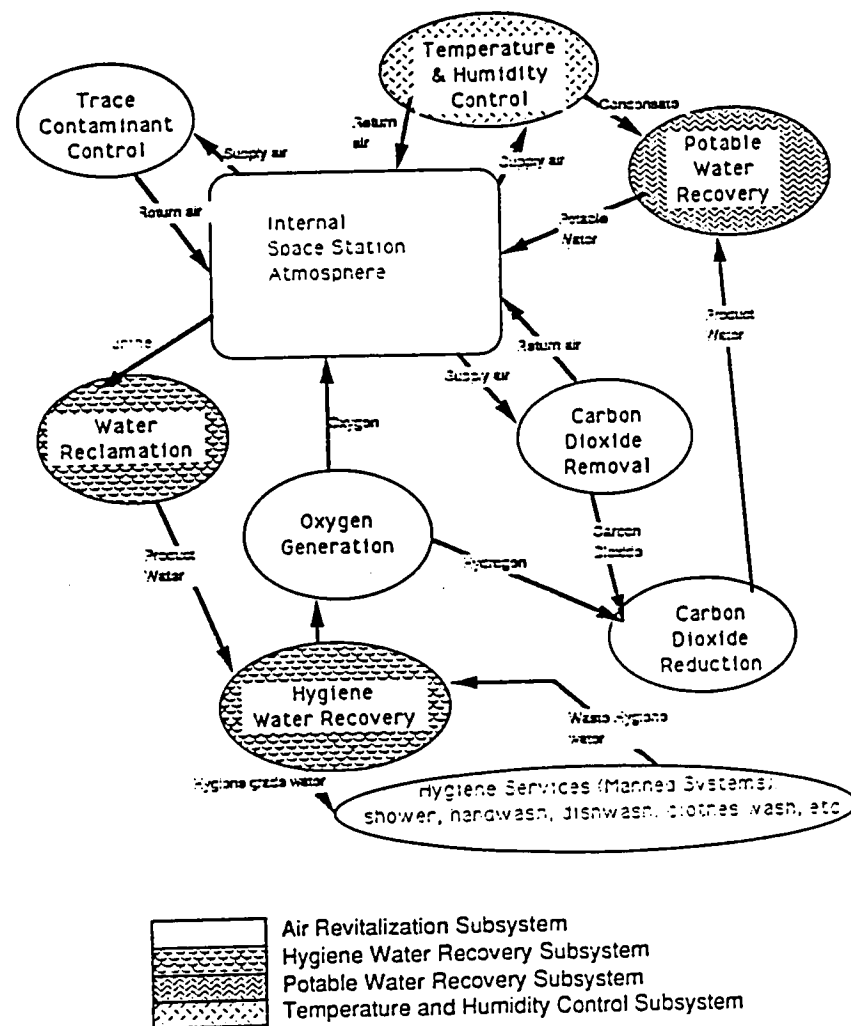
Figure 1 - Regenerative ECLSS Functional Interfaces

3) Object-oriented, Distributed Chemical and Microbial Modelling of Regenerative Environmental Control Systems Description (continued)

Description (continued)
Inputs, transfer functions, and outputs for each subsystem (including chemical, microbial, and process control data) can be independently enhanced.

New technology subassembly and biological models can be exchanged with the old models to analyze effects.

A network acts as the integrating agent.

Evolutionary Space Station ECLSS, Lunar Base, and Mars Mission regenerative environmental control systems development can use such a modelling system with a closed environment testbed to determine the effects, including chemical and microbial closed loop stability, of implementing:

- Evolutionary Space Station ECLSS process control technologies
- Lunar oxygen mining operations
- Plants and biomass systems

Analysis and modelling of closed loop environmental control systems may enhance our knowledge of, or provide a structure for analysis of, inherent instabilities in the Earth environment.

Approach
Each node in the testbed network can be either a subassembly model or an actual subassembly under test. Shared environmental data can come from the closed environment testbed or model. Subsystem and their models, developed by independent subsystem developers, can be added to the network.

The modelling system should be verified and enhanced in a ground closed environment testbed, and compared with micro-gravity results from Space Station data. Some unexpected chemical and microbial combinations may take place due to changes in fluid mixing behaviors in micro-gravity.

OBJECT MODEL FOR EACH PROCESS
(INCLUDING OPEN ATMOSPHERE AND
CREW)

Chem. IN →

Microb IN →

Pressure →

Temp →

Flow →

Environmental Parameters →

INPUTS

PROCESSING:
- BEGINS AS TABLE LOOKUP FOR EACH SUBASSEMBLY PROCESS.
- ACCURACY INCREASED DURING ANALYSIS AND TEST.
- CHEMICAL AND MICROBIAL TRANSFER FUNCTIONS HAVE GRAVITY COEFFICIENTS

OUTPUTS

↓ Chemical Constituents ↓ Microbial Constituents ↓ Temp ↓ Flow
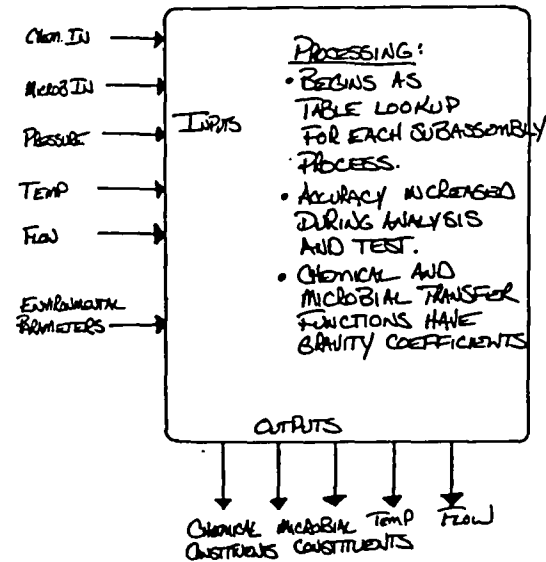
EVOLUTIONARY ECLSS ENGINEERING TESTBED

| THC | PWR | HWR | UPA | AWOM |

| CIC | ACMA | CRA | OGA |

SE

CENTRAL DATA SHARED / TEST CNTL

DISPLAY WKSTN / FDI / 28MS MODEL
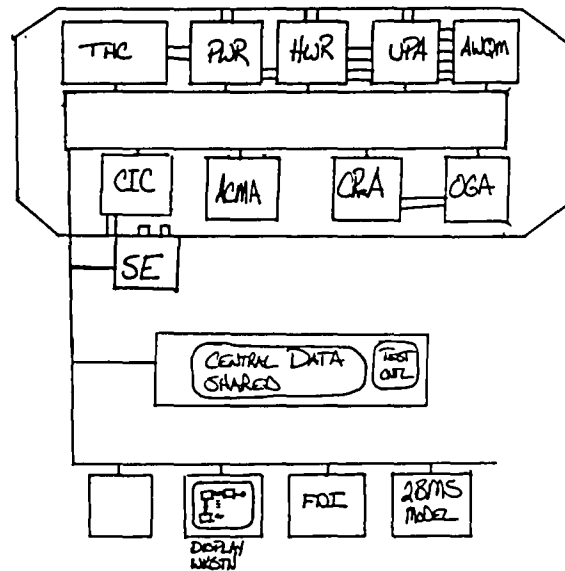
Conclusion Description

In our Environmental Control and Life Support System automation analysis we found three areas which definitely need further research and development: Automatic fault diagnosis of ECLSS subsystems, in-line real-time chemical and microbial water analysis, and object-oriented distributed chemical and microbial modelling of regenerative environmental control systems.

The Space Station ECLS System should act as a testbed for each of these research areas, as it is for automatic fault diagnosis of process control systems in the ECLSS Advanced Automation Project. Modelling of chemical and microbial closed loop interactions should begin immediately in order that our knowledge may be verified on the ground and on board in time for future missions.

We have entered into an exciting time for man-made regenerative environments. With further research in chemical and microbial interactions, the Space Station environmental control system can be used as a spring board to increase man's knowledge of all existing and envisioned closed environments.

Conclusion

* Automatic fault diagnosis of ECLSS subsystems

* In-line real-time chemical and microbial water
    analysis, and

* Object-oriented distributed chemical and microbial
    modelling of regenerative environmental control
    systems.

* The Space Station ECLS System should act as a testbed
    for each of these research areas.

* Modelling of chemical and microbial closed loop
    interactions should begin now.

* Joint ventures between research centers and development
    centers are necessary to increase man's knowledge in
    regenerative environments.

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Marshall Space Flight Center
ECLSS Technology Activities

Paul Wieland
Life Support Branch/ED62

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p. 31

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ONGOING MSFC LIFE SUPPORT ACTIVITIES
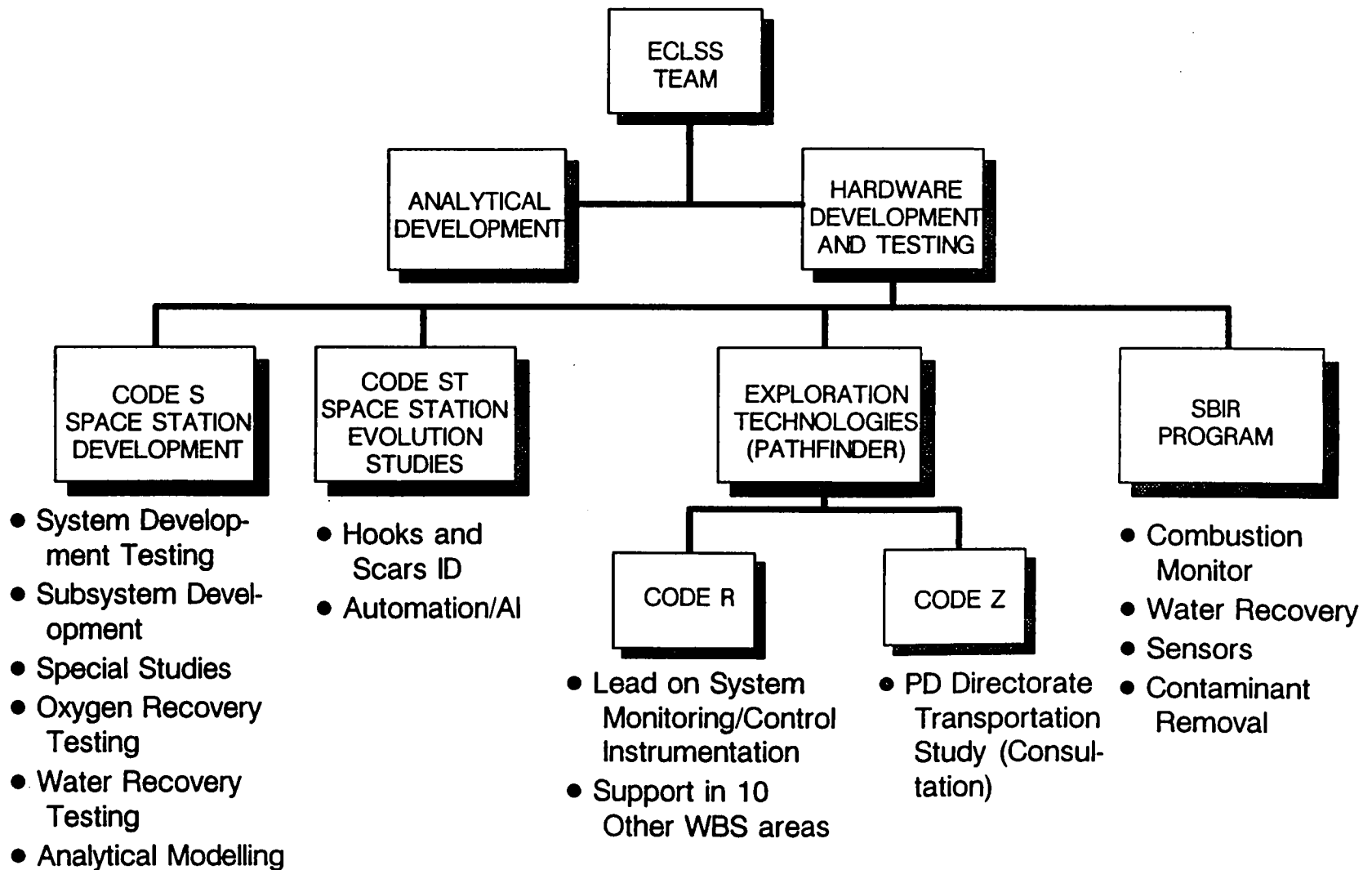
ECLSS
TEAM

ANALYTICAL
DEVELOPMENT

HARDWARE
DEVELOPMENT
AND TESTING

CODE S
SPACE STATION
DEVELOPMENT

CODE ST
SPACE STATION
EVOLUTION
STUDIES

EXPLORATION
TECHNOLOGIES
(PATHFINDER)

SBIR
PROGRAM

- System Develop-
  ment Testing
- Subsystem Devel-
  opment
- Special Studies
- Oxygen Recovery
  Testing
- Water Recovery
  Testing
- Analytical Modelling

- Hooks and
  Scars ID
- Automation/AI

CODE R

CODE Z

- Lead on System
  Monitoring/Control
  Instrumentation
- Support in 10
  Other WBS areas

- PD Directorate
  Transportation
  Study (Consul-
  tation)

- Combustion
  Monitor
- Water Recovery
- Sensors
- Contaminant
  Removal

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ANALYTICAL
DEVELOPMENT

569

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570

ECLSS MODELING APPROACH

- TOP LEVEL EFFECTS
- MASS BALANCE CONSIDERATIONS ONLY
- RESOURCE ASSESSMENTS, MASS BALANCE SENSITIVITIES

- INTERACTIONS BETWEEN SYSTEMS/MODULES
- FURTHER SIMPLIFICATION OF PHYSIOCHEMICAL EFFECTS
- SYSTEM/MODULE INTERACTIONS

- INTERACTIONS BETWEEN SUBSYSTEMS/COMPONENTS OF SUBSYSTEMS
- SIMPLIFY ASPECTS OF PHYSIOCHEMICAL EFFECTS
- SUBSYSTEM INTERACTIONS

- INSIDE "BLACKBOX"
- PHYSICAL, CHEMICAL THERMODYNAMIC EFFECTS ON MICROSCOPIC LEVEL
- SUBSYSTEM/COMPONENT PERFORMANCE

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571

ECLSS ANALYTICAL AREAS

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ANALYTICAL MODEL NEEDS

- **Detailed (of components and subsystems, for subsystem design and assessment)**
  e.g., membrane transport evaluation
  - macroscopic/microscopic theory incorporation into detailed "1st principles" models
  - extensive "phenomological level" test data to support model development
  - theory for microbial model development
  - multi-component chemical interaction models

- **System-module (for subsystem groups, design and assessment)**
  e.g., detailed transients for water tank sizing
  - simplifications of the above models, which represent detailed processes to good fidelity
  - system interaction data
  - large/fast computers
  - CASE/A program improvements

- **System-intermodule (for validation models)**
  e.g., pressurized volume CO_2 level prediction
  - further simplification of the above system-module models
  - large, fast computers
  - CASE/A program improvements

- **Top level (for resource assessments)**
  e.g., resupply needs
  - better input data

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EXAMPLE OF WATER RECLAMATION MODELING NEEDS

CURRENT CAPABILITIES:
- System level representations of water processing operations
  - distillation (TIMES, VCD)
  - reverse osmosis
  - multifiltration (particulate filtration, adsorption, ion exchange)

- "Curve fit" performance simulations of production rate, sensible loads, etc.

- Contaminant rejections (and therefore product water quality) from supplier-defined efficiencies

REQUIRED CAPABILITIES:
- Detailed models based on the thermodynamic and physiochemical phenoena occurring within the processes

- Impacts of physiochemical interactions
  - solute/solute
  - solute/solvent
  - solute/process
  - solvent/process

- Ability to predict transient performance and water quality

TECHNICAL CHALLENGE:
- State–of–the–art modeling limited, at best, to wastewater systems containing 2 or 3 known solutes
- Extension of bi–solute or tri–solute models to multi–solute systems is currently very limited

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575

HARDWARE
DEVELOPMENT
AND
TESTING

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MSFC ECLSS Hardware Development Activities

I.   **Code S – Space Station Freedom**
  A.   Phase I Independent Subsystem Testing (1986–present)
  B.   Phase II Integrated Testing (1987)
  C.   Phase III Integrated Testing (1989–1990)
  D.   Subsystem Comparative Testing (BA) (1989–1990)
  E.   Operational System Tests (1989–1993)
  F.   Microbial Ecology Lab Studies

II. **Code ST – Space Station Freedom Evolution**
  A.   ECLSS Evolution and Evaluation For Hooks And Scars
  B.   Automation/Artificial Intelligence

III. **Code R – Exploration Technologies (Pathfinder)**
  A.   Sensor Development
  B.   Trace Organic Removal Process Development
  C.   Trace Contaminant Monitoring Technology Development

IV. **Code Z – Exploration Studies (Program Development Directorate)**

V.   **SBIR – Small Business Innovation Research Program**
  A.   Phase I 1989 awards
    1.   "Incipient Combustion Monitor for Zero Gravity Environments"
    2.   "A Reagentless Separator for Removal of Inorganic Carbon From Solution"
    3.   "Thin Membrane Sensors"
  B.   Phase II 1989 awards
    1.   "Catalytic Water Purification Development"

VI. **University Involvement**
  A.   University of Alabama in Huntsville
  B.   University of Wisconsin
  C.   Harvard (funding: 80% ARC, 20% MSFC)
  D.   Georgia Institute of Technology

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ΝΛSΛ

Code S – Space Station *Freedom*

Phase I Independent Subsystem Testing (1986–present)

Objectives: Verification that the subsystems operate properly and familiarization of personnel with subsystem operation, acquisition of performance data, verification of integration requirements in anticipation of later integrated testing, identification of any special problems, determination of off–nominal performance.

Subsystems Tested:

CO_2 Removal –   Four–Bed Molecular Sieve (4BMS)
Solid Amine Water Desorbed (SAWD)
Electrochemical Depolarized Cell (EDC) [planned]
Two–Bed Molecular Sieve (2BMS)

CO_2 Reduction –   Sabatier
Bosch

O_2 Generation –   Static Feed Electrolyzer (SFE)

Water Reclamation – Thermoelectric Integrated Membrane Evaporation System (TIMES)
Vapor Compression Distillation (VCD)

Trace Contaminant Control –   Trace Contaminant Control Subsystem (TCCS)

Results: Operation and performance of the subsystems evaluated, special integration considerations identified, subsystem anomalies identified.

577

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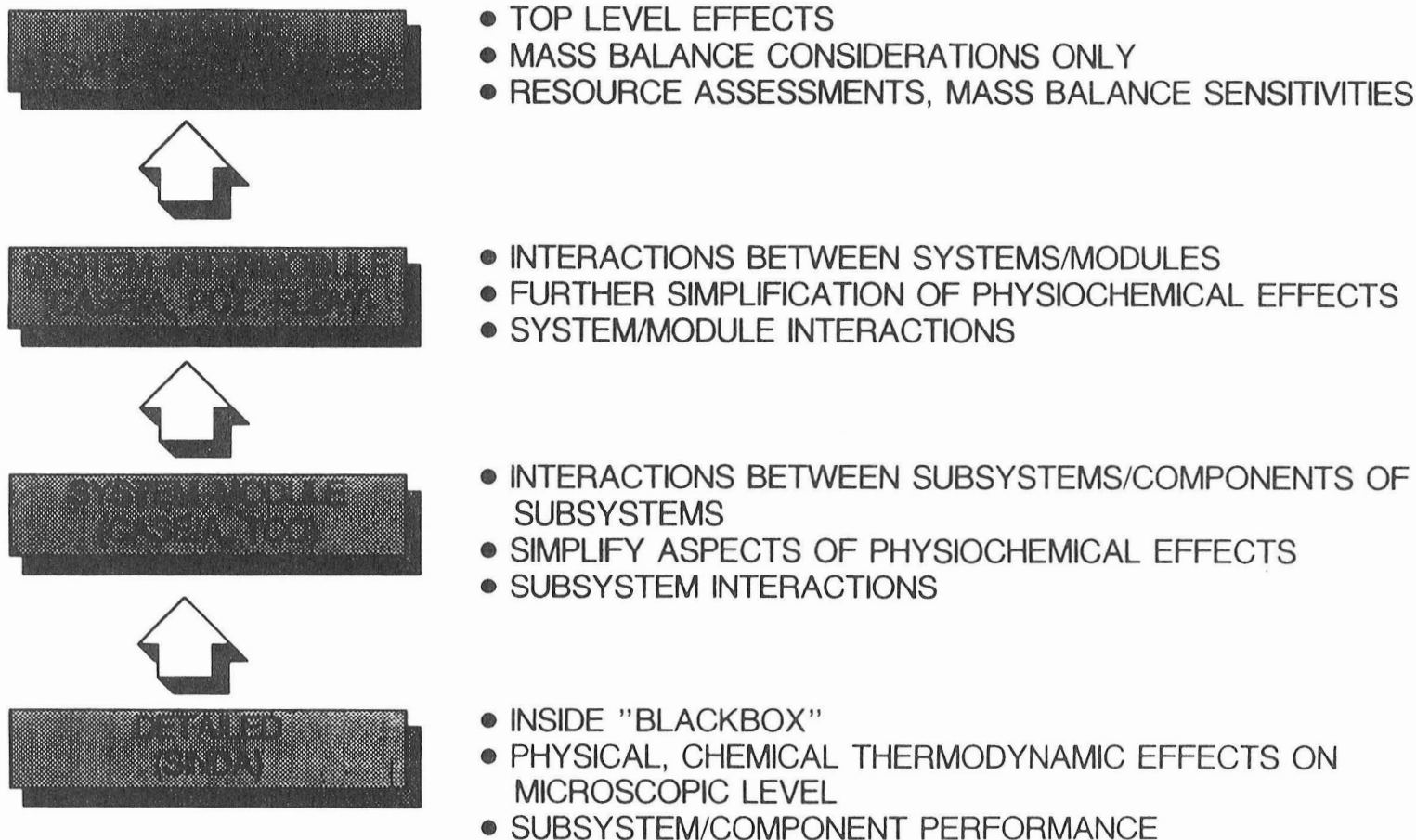
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Code S – Space Station *Freedom*

Phase II Integrated Testing (1987)

Simplified Integrated Test – 42 hours of "open door" integrated operation (June 1987)
Metabolic Control Test – 148 hours of "closed door" integrated operation (November 1987)

Objectives: Verify proper operation of the ECLSS subsystems when integrated and gather performance data for the partial ECLS system used in the test.

Subsystems Tested: 4BMS, Sabatier, SFE, TIMES, TCCS

Results: Demonstrated the feasibility of operating and maintaining an integrated ECLS system for an extended period, provided baseline data about the stability of an ECLS system, and pointed out what developments and improvements are needed to conduct future integrated ECLS system tests. The knowledge gained is then incorporated into the design of the next generation subsystems.

The results are documented in:
"Space Station ECLSS Simplified Integrated Test Final Report" NASA TM–100363, March 1989,
and "Space Station CMIF Extended Duration Metabolic Control Test Final Report" NASA TM–100362, March 1989.

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Phase III Integrated Testing (1989-1990)

Simplified Integrated Test – 256 hours total of "open door" with 148 hours of integrated operation (August 1989)

Subsystems: 4BMS, Bosch, SFE, TCCS

Objectives: Investigation of system integration of the Space Station air revitalization subsystems, operation of the Bosch until cartridge "switchover" occurs.

Results: Preliminary report expected to be released in November.

Water Recovery Test – Testing of the water recovery subsystems planned for February 1990.

Subsystems: Multi-filtration, Reverse Osmosis, Water Quality Monitor (TOC), TIMES, VCD

Objectives: A major objective is to include people in the loop to provide hygiene water and to drink reclaimed potable water. Water analysis techniques are being developed and verified to ensure quality control and quality assurance during analysis of samples.

Waste water to be reclaimed includes: perspiration, respiration, urine, shower water, and water from a hand washer, a clothes washer, and a dish washer. These waste waters will be generated in the End-use Equipment Facility (EEF) which is a 100K clean room where the test subjects and equipment (exercise, etc.) are located.

An Institutional Review Board (IRB) has been established in accordance with NMI 7100.8A to review protocols and procedures for ECLSS testing using human subjects. This board will address the institutional safety, medical, and legal requirements associated with human research.

Metabolic Control Test – Integrated testing planned to begin in mid-1990 for three months.

Subsystems: 4BMS, Bosch, SFE, TCCS, TIMES, RO, MF, VCD

Objectives: Integration of the Space Station air revitalization and water recovery subsystems.

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580

NEW ECLSS PHASE III TEST SCHEDULE (10/23/89)

May 1989

CALENDAR YEAR	1989												1990											
MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

SUBSYSTEM TESTING

AIR REVITALIZATION

- MOLECULAR SIEVE — I & C/O
- SFE — I & C/O
- TCCS — I & C/O
- BOSCH — I & C/O

WATER RECOVERY

- MULTI-FILTRATION — I & C/O
- REVERSE OSMOSIS — I & C/O
- WQM (TOC)
- TIMES — I & C/O
- VCD — I & C/O

ECLSS PDR

SYSTEM TESTING

- INDEPENDENT SUBSYS TEST
- AIR REVITALIZATION SIMPLIFIED INTEGRATED TEST (SIT) (5 DAYS)
- WATER RECOVERY TESTS
- METABOLIC CONTROL TEST (MCT) (4 DAYS)
- EXTENDED DURATION METABOLIC CONTROL TEST (30 DAYS)
- TRANSIENT CONTROL TESTS (14 DAYS)

LEGEND

- Subsystem Functional Tests
- Subsystem/System Performance Tests
- Integration and Checkout

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CALENDAR YEAR	1989												1990											

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Prime Contractor Subsystem Comparative Testing
(1989–1990)

Independent Subsystem Testing (Boeing Aerospace) – beginning late 1989

Objective: Evaluation of prototype hardware of comparable maturity and with the same test conditions, for performance, safety, reliability, servicing and maintenance requirements.

Subsystems: CO_2 Removal – Four–Bed Molecular Sieve (4BMS)

CO_2 Reduction –   Bosch
                      Sabatier

O_2 Generation – Static Feed Electrolyzer (SFE)
                    Anode Feed Solid Polymer Electrolyte (AFSPE)

Waste Water Reclamation
    Urine Recovery –   Thermoelectric Integrated Membrane Evaporation System (TIMES)
                        Vapor Compression Distillation (VCD)

    Hygiene Water –   Reverse Osmosis (RO)
                       Multi–Filtration (MF)

    Potable Water Recovery – Multi–Filtration (MF)
                              Reverse Osmosis (RO)

Results: Final selections of the subsystems to be used on the Space Station *Freedom* will be based on the results of these tests.

581

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Prime Contractor Operational System Tests
(1989–1993)

Concept Confirmation Tests (CCT) – 1989–1990

    Testing avionics air flow control to equipment racks and fire suppressant flow control concepts.

Predevelopment Operational System Test (POST) – 1990

    Early evaluation of the baseline concepts, verification of operating interfaces, acquisition of data prior to CDR.

Early Race Track (ERT) – April 1991

    Operational evaluation of the inter–element air circulation system, verification of the ability to control ventilation requirements from centralized locations.

Baselined Operational System Test (BOST) – 1992

    Verification of flight qualifiable hardware including a 30–day unmanned test.

Manned Operational System Test (MOST) – January 1993

    Includes a 90–day manned test. After completion of the test the subsystems will be refurbished and delivered to JSC for further testing.

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CORE MODULE INTEGRATION FACILITY
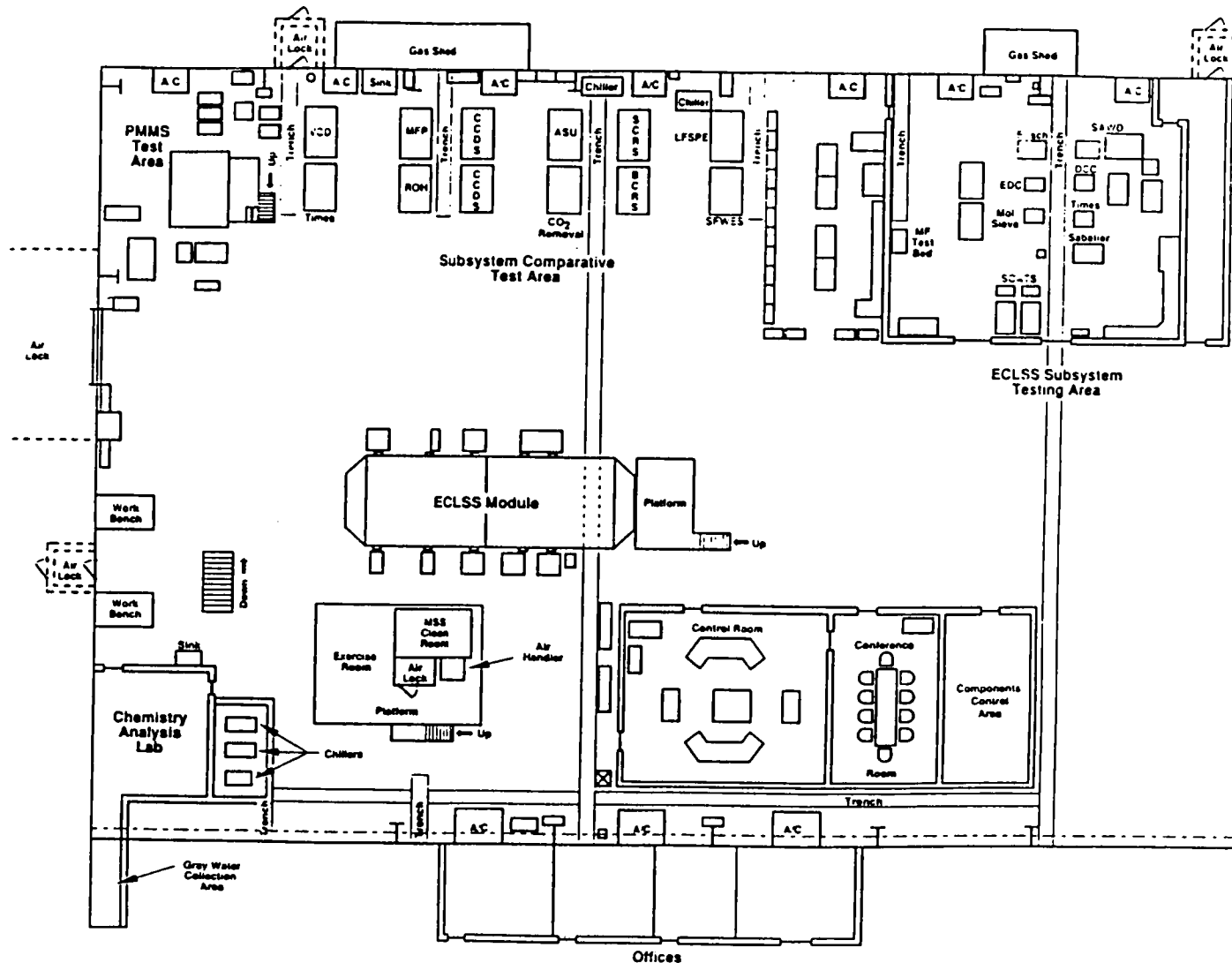
584

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EARLY RACK TRACK LOCATION IN 4755

585

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MOST CONFIGURATION IN 4755

SECURE STORAGE AREA

Air Lock

Air Lock

MOST

CREW QUARTERS

ECLSS Subsystem Testing Area

ECLSS Subsystem Testing Area

ENGINEERING MODEL (ETA)

CONTROL ROOM

ECLSS Module

RACK CHECK-OUT

Chemistry Analysis Lab

Gray Water Collection Area

Offices

Technology for Space Station Evolution
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NASA

ECLSS DEVELOPMENT TEST PROGRAM

1987	1988	1989	1990	1991	1992	1993	1994	1995

PHASE I

PHASE II

CMF

CMF

PHASE II

MSFC IN-HOUSE ACTIVITIES

CONCEPT CONFIGURATION TESTS

FLOW-POST OPERATIONAL TEST

COMPARATIVE TESTS

ECLSS EARLY RACETRACK

BOST

CREW QUARTERS

MOST

COMMON MODULE

FLIGHT QUALIFICATION ARTICLE

BOEING PHASE C/D CONTRACT ACTIVITIES

NOTE:
POST -- PROTOTYPE OPERATIONAL SYSTEM TEST
BOST -- BASELINE OPERATIONAL SYSTEM TEST
MOST -- MANNED OPERATIONAL SYSTEM TEST

587

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Code S – Space Station *Freedom*

MSFC Microbial Ecology Lab Studies

Purpose: (1) Provide routine sampling and microbiological identifications for ECLSS test activities.

(2) Conduct research leading to predictive models of behavior of microorganisms in the closed loop environment of Space Station *Freedom*.

(3) Provide test information on the effects of microbial growth on materials to be used on Space Station *Freedom*.

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Code ST – Space Station *Freedom* Evolution

ECLSS Evolution

OBJECTIVE: This task will develop and apply the analytical tools needed to allow the ECLSS to evolve in a manner such that it meets the needs of the users over the long term, and will also identify hooks and scars required to implement the selected growth technologies.

APPROACH:
- Conduct a survey to identify ECLSS technologies with growth option potential
- Develop a prioritized list of candidates and perform an IOC hook and scar assessment
- Expand the existing analysis tools
- Perform a comparative analysis against the IOC system
- Perform cost/benefit trade studies based on the analysis

PRODUCTS:
- Interface requirements/performance characteristics/figures of merit
- Preliminary hooks and scars requirements
- CASE/A component models and documentation
- Comparative data
- Final report

STATUS: A preliminary study has been done and a contract to perform the full study is in the process of being awarded.
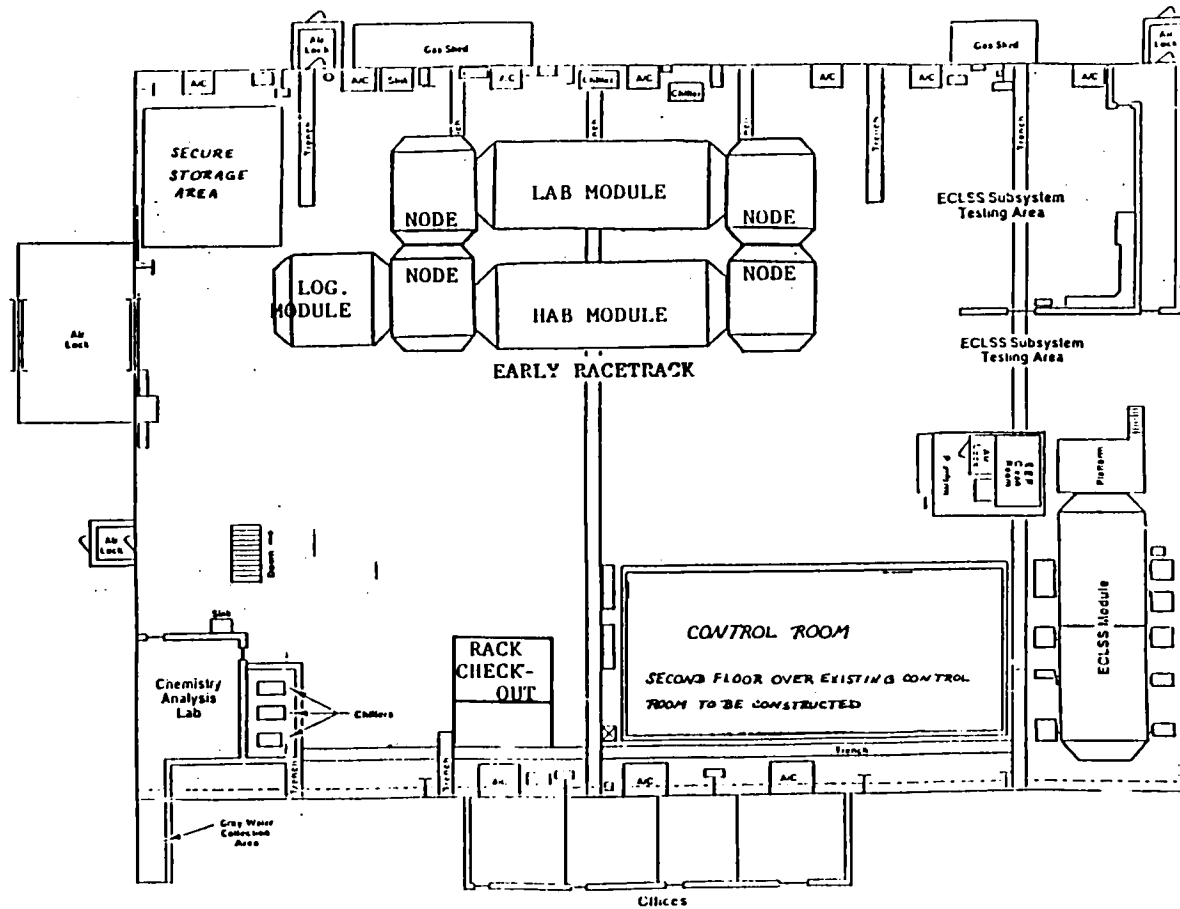
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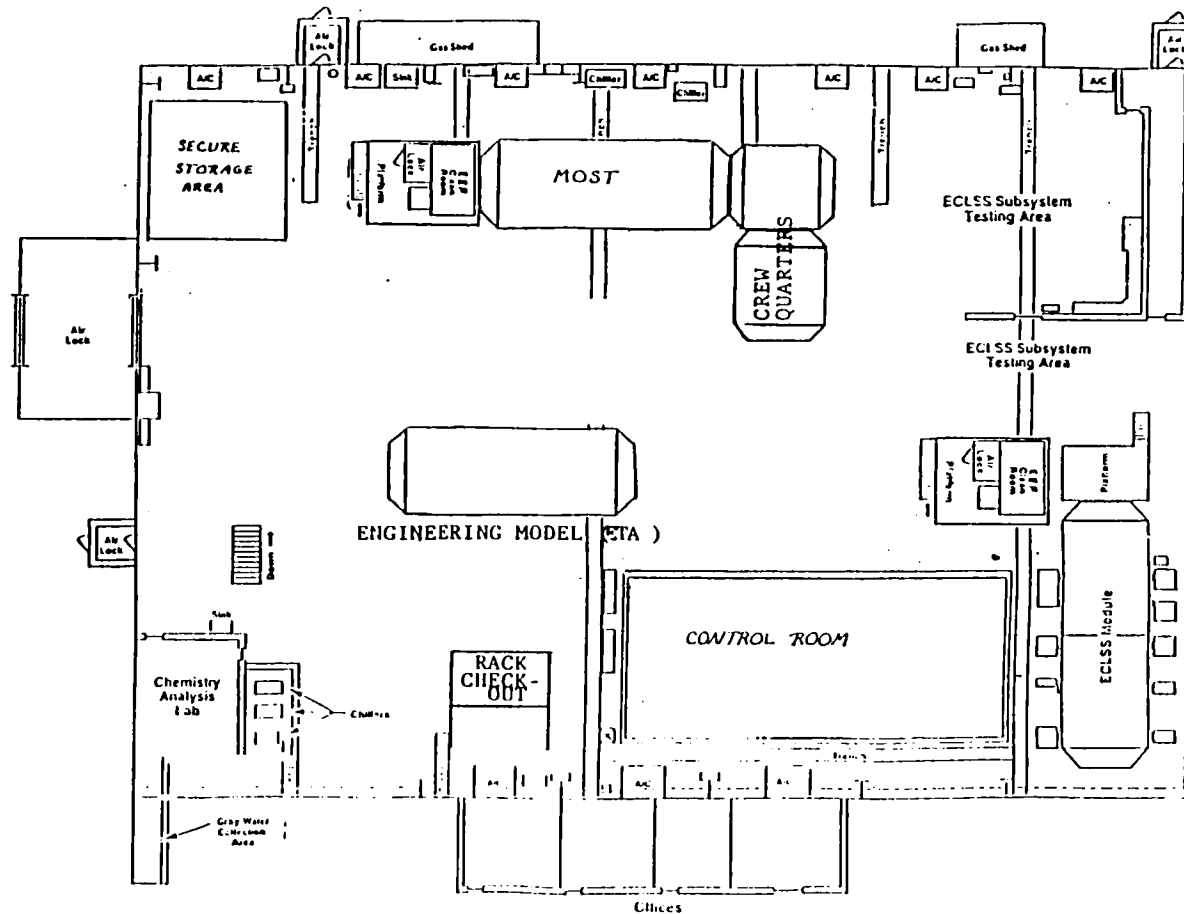Technology for Space Station Evolution
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Code ST – Space Station *Freedom* Evolution

ECLSS Advanced Automation

OBJECTIVE: To design, test, and evaluate Knowledge Based System (KBS) components for the ECLSS which will assist the crew and increase system autonomy.

APPROACH:
- Phase 1
  - Establish the KBS requirements
  - Determine the hooks, scars, and interfaces
  - Study KBS research and techniques in NASA and industry
  - Begin initial prototyping of ECLSS advanced automation software components

- Phase 2 – Initial proof of concept design and development

- Phase 3 – Implementation and testing of the KBS on actual subsystem hardware
    (ECLSS test bed in Building 4755 at MSFC)

PRODUCTS:
- Documentation – reports, development plan, design & test specifications
- Hardware – Software Support Environment (SSE) compatible workstation integrated into the software development environment
- Software – ECLSS KBS with Ada knowledge based system shell, integrated with the SSE software tools
- Final system – KB system(s) ready to be integrated with ECLSS hardware and software

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Code R – Exploration Technologies (Pathfinder)

MSFC is the lead for Systems Monitoring and Control Instrumentation.

RTOP #591-34-61 System Monitoring, contract with MDSSC
"real-time sensor" development
chemical composition monitoring technology

RTOP #591-34- ECLSS Evolution and Advanced Instrumentation, new contract
continuation of 591-34-61 effort

RTOP #591-34- Trace Contaminant Monitoring

In support of 10 other WBS categories MSFC has one water recovery technology task.

RTOP #591-34-21 Water Recovery, contract with MDSSC, subcontracted to Sievers
Research trace organic removal water reclamation (funded through
Ames)

591

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592

CODE R PATHFINDER
NASA CENTER ROLES – P/C CLLS OFFICE

	ARC	JPL	JSC	LaRC	MSFC
1.1 PHYSICAL/CHEMICAL LIFE SUPPORT					
1.1.1 THERMAL CONTROL	S		L		S
1.1.2 AIR REVITALIZATION	S	S	L		S
1.1.3 WATER MANAGEMENT	L	S	S		S
1.1.4 SOLID WASTE MANAGEMENT	L	S	S		S
1.1.5 FOOD MANAGEMENT	S		L		S
1.2 PORTABLE LIFE SUPPORT SYSTEMS					
1.2.1 THERMAL CONTROL SYSTEMS	SEE EVA/SUIT				
1.2.2 ATMOSPHERE CONTROL	PROJECT PLAN				
1.2.3 MONITORING & CONTROL	FOR DETAILS				
1.2.4 SYSTEM INTEGRATION					
1.3 SYSTEMS CONTROL					
1.3.1 SYSTEMS MONITORING & CONTROL INSTR.	S				L
1.3.2 SYSTEMS CONTROL STRATEGY	L				S
1.4 SYSTEM INTEGRATION					
1.4.1 SYSTEM REQUIREMENTS	S	S	L		
1.4.2 P/C BIO SYSTEMS	L	S			
1.4.3 SYSTEMS ANALYSIS & ASSESSMENT	L	S	S	S	S
1.4.4 VALIDATION & VERIFICATION	L		S		S
1.4.5 SYSTEM TESTS	L		S		S
1.4.6 HUMAN-RATED TESTS	S		L		S

L = LEAD CENTER
S = SUPPORT CENTER

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Code R – Exploration Technologies (Pathfinder)

Sensor Development Needs

- Water Quality Monitor (WQM) –   on–line

    - Specific contaminants/mechanical properties
    - Improvement in Trace Organic Contaminant (TOC) sensitivity

- Water Quality Monitor (WQM) –   off–line

    - Automation

- Trace gas analyzer

    - Automation
    - Turn–around time

- Specific hazardous gas sensors

    - Hydrogen
    - Methane
    - Other hazardous payload substances

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Code R – Exploration Technologies (Pathfinder)

Other Need Areas

● Different Subsystem Selection Because of:
  - ● Space Station shortfalls
  - ● Design differences – e.g., propulsion other than O_2/H_2, venting allowed, 90–day resupply, photovoltaic power supply, etc.
  - ● Different weighting factors and priorities
    - – power
    - – weight
    - – volume
    - – other
  - ● New technology breakthroughs
    - – automation improvements
    - – improvements/maturing of existing P/C processes
    - – advancements in P/C processes
    - – CELSS

● System Differences
  - ● Mission scenarios different from the Space Station
  - ● Local resource usage capability
  - ● Mission isolation with no resupply

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Code Z – Exploration Technologies

PD Directorate Transportation Studies Support
- Review Technical Content of Contract Studies
- Act as an Advisor to PD Personnel
- Support Reviews
- Provide PD/Contractor Personnel SSF Data and Consultation

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Phase I Small Business Innovation Research Contract's

1. TITLE: "Incipient Combustion Monitor for Zero Gravity Environments"
   CONTRACT: TBD (SBIR '89 Phase I)   CONTRACTOR: ADA Technologies, Inc.
   PERIOD OF PERFORMANCE: 1/90 – 7/90

   GOAL: To investigate the feasibility of using a dynamic expansion condensation nuclei chamber for the detection of submicron particles emitted when combustible materials are heated.

2. TITLE: "A Reagentless Separator for Removal of Inorganic Carbon from Solution"
   CONTRACT: TBD (SBIR '89 Phase I)   CONTRACTOR: Umpqua Research Co.
   PERIOD OF PERFORMANCE: 1/90 – 7/90

   GOAL: To investigate removing inorganic carbon by first converting it to CO_2 using a solid–phase acidic material and then separating it using a CO_2 permeable membrane degasser.

3. TITLE: "Thin Membrane Sensors"
   CONTRACT: TBD (SBIR '89 Phase I)   CONTRACTOR: Resource Technologies Group, Inc.
   PERIOD OF PERFORMANCE: 1/90 – 7/90

   GOAL: To investigate the feasibility of using a thin membrane sensor with controllable electrical properties to detect a variety of chemical and biological agents.

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Phase II Small Business Innovation Research Contract's

TITLE: "Removal of Contaminants From Experiment Waste Water Using Immobilized Enzymes"
CONTRACT: NAS8-37642 (SBIR '87 Phase I)   CONTRACTOR: Umpqua Research Co.
PERIOD OF PERFORMANCE: Phase I: 1/88 – 7/88, Phase II: 1/90 – 12/91

GOAL: To investigate the use of immobilized enzymes to enhance the removal of low molecular weight organic contaminants from the Process Materials Management System (PMMS) and ECLSS wastewaters

PHASE I RESULTS:
- Two enzymes were focused on:
    - urease (for removal of urea)
    - alcohol oxidase (for removal of methanol, ethanol, and related contaminants)
- Both enzymes successfully immobilized the contaminants
- Good performance was demonstrated

PHASE II PROPOSAL:
- Continue development to:
    - optimize enzyme preparation and immobilization methodologies
    - investigate synergistic effects through co–immobilization of complementary enzymes
    - investigate additional enzymes to broaden the range of contaminants removed
    - develop and test alternate reactor designs
    - perform long term parametric and life testing
    - fabricate and deliver prototype reactors to the MSFC for testing
- Contract awarded 12/89

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University Involvement

University of Alabama in Huntsville –
"Identifying Critical Monitoring Tests for Recycled Water Systems"

University of Wisconsin –
Developing a Predictive Model of the Ecological Behavior of Microorganisms
Developing Techniques and/or Equipment Which Facilitate Rapid Monitoring of Microorganisms

Harvard (funding: 80% ARC, 20% MSFC) –
"Processes Involved in Microbial Biofilm Formation in Water Reclamation Systems for the Orbiting Space Station"

Georgia Institute of Technology –
"CO_2 Reduction Subsystem Combustion Kinetics"

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Technology for Space Station

Evolution Workshop

JSC ECLSS R&T Program Overview

Dallas, TX

January 16-19, 1990

A.F. Behrend

NASA - JSC

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Content

- **Advancements in Electrochemical CO2 Removal**

- **Supercritical Water Waste Oxidation**

- **Electrooxidation for Post-treatment of Reclaimed Water**

- **Photocatalytic Post-Treatment of Reclaimed Water**

600

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Advancements in Electrochemical CO2 Removal

Objective

- Investigate and develop fundamental process enhancements in electrochemical CO2 removal

Benefit

- Improve performance and reliability

  - CO2 removal efficiency improvement (5-10% improvement achieved)

  - Cell composition improvement

  - Hydrogen feed elimination

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Advancements in Electrochemical CO2 Removal

Technical Description

- Air passes through electrochemical cell where CO_2 is absorbed at cathode and evolved at anode

- Electrochemical CO_2 removal with hydrogen utilizes alkaline hydrogen/oxygen fuel cell reaction

  - O_2 from air supplied at cathode where CO_2 is absorbed

  - H_2 supplied at anode where CO_2 is evolved

  - CO_2 reacts with hydroxyl ions (OH^-) to form carbonate and bicarbonate ions ($CO_3^=$ and HCO^-) which migrate to anode where heat energy from the fuel cell reaction releases the CO_2

  - Half-cell reactions at both electrodes are thermodynamically spontaneous

  - Process generates electricity

- Same process can be carried out without supply of hydrogen

  - Series of reactions not spontaneous

  - Power must be supplied (approximately 105W/per person)
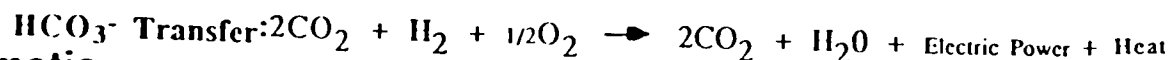
602

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Advancements in Electrochemical CO2 Removal

$CO_3^=$ Transfer: $2CO_2 + 2H_2 + 2O_2 \longrightarrow 2H_2O + 2CO_2 +$ Electric Power + Heat

HCO_3^- Transfer: $2CO_2 + H_2 + 1/2O_2 \longrightarrow 2CO_2 + H_2O +$ Electric Power + Heat
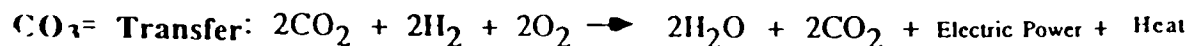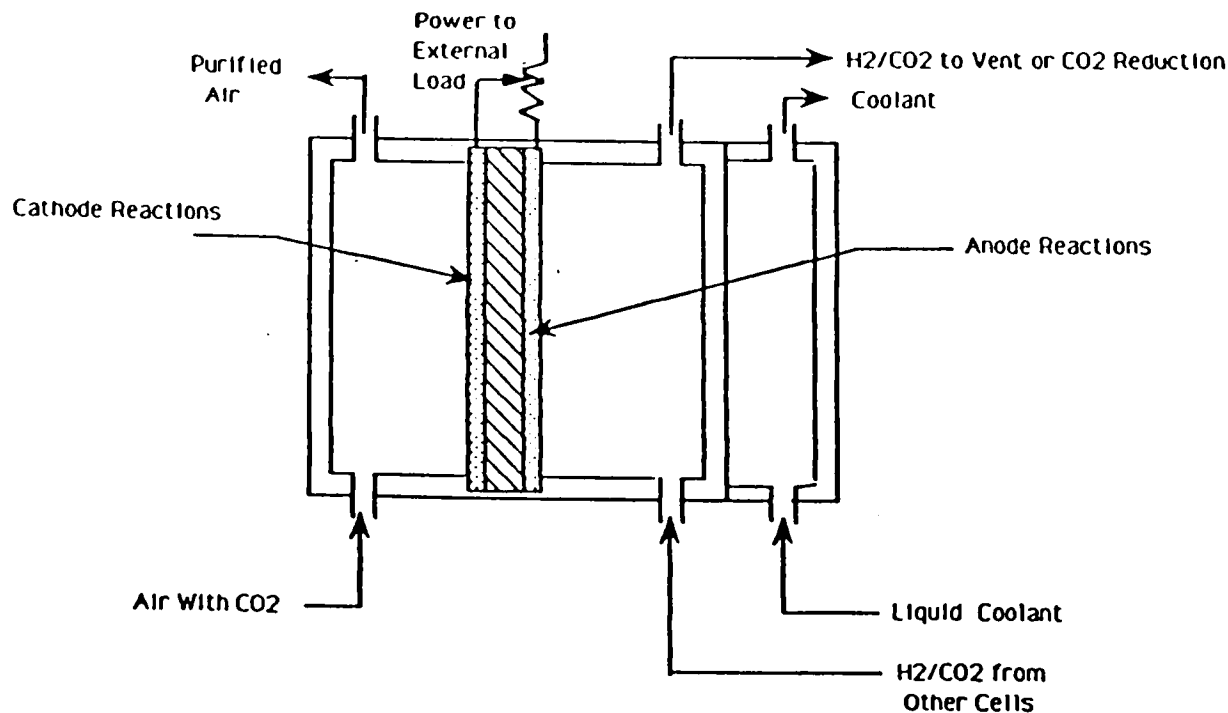
Schematic

Electrochemical Carbon Dioxide Removal with Hydrogen

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Advancements in Electrochemical CO2 Removal

$$CO_3^= \text{ Transfer: } CO_2 + 1/2O_2 \rightarrow CO_2 + 1/2O_2$$

$$HCO_3^- \text{ Transfer: } 2CO_2 + 1/2O_2 \rightarrow 2CO_2 + 1/2O_2$$

Schematic

- Purified Air
- Power from External Source
- O2/CO2 to Vent of CO2 Reduction
- Coolant
- Cathode Reactions
- Anode Reactions
- Air With CO2
- Liquid Coolant
- O2/CO2 from Other Cells

Electrochemical Carbon Dioxide Removal without Hydrogen

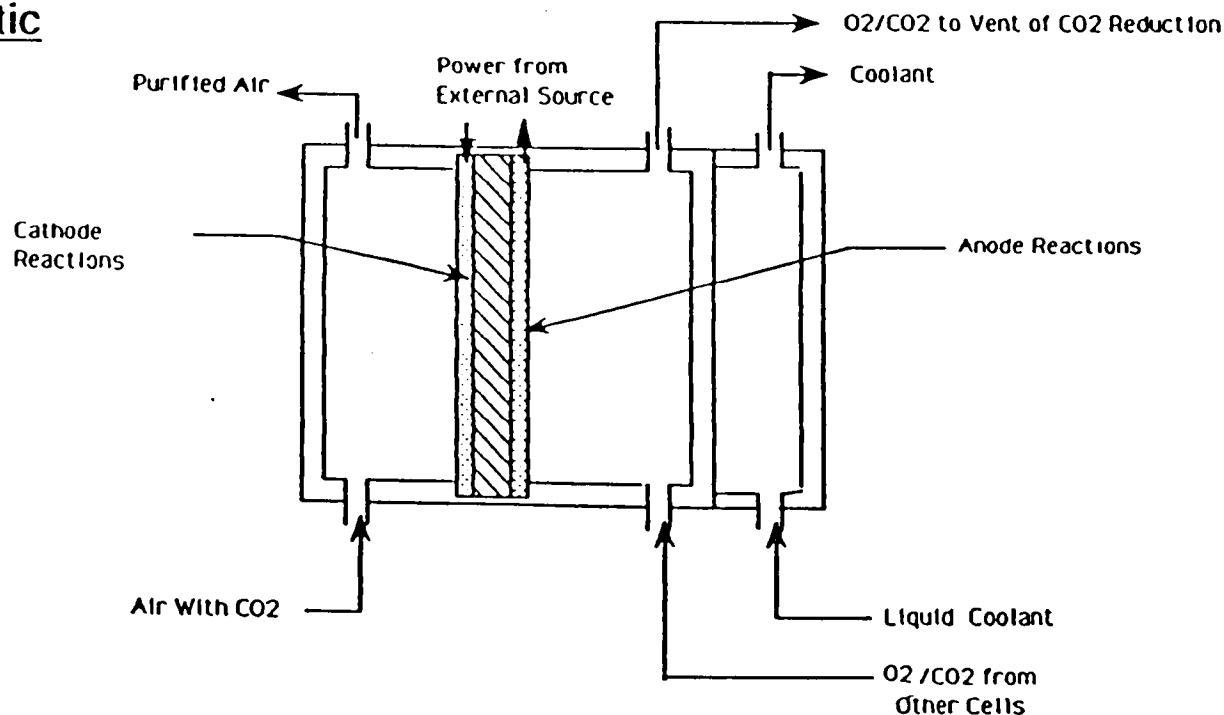| Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
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Advancements in Electrochemical CO2 Removal

Status

- **Program with Life Systems, Inc./Texas A&M; Initiated in December 1987**

- **2 year Phase I to investigate and develop fundamental process enhancements**

  - **Literature review to identify areas of study for improved performance and operational flexibility**

  - **Bench-scale laboratory testing of cell components to identify best candidates for integrated testing**

  - **Single cell unit design, fabrication, and testing**

- **Single cell testing being completed now**

- **1 year Phase II for multi-cell unit design, fabrication, and test**

605

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Advancements in Electrochemical CO2 Removal

Results

- Determined optimum electrocatalyst loading and binding agent content for gas diffusion electrodes

- Developed an improved electrode fabrication method using ultrasonic device for the dispersion of gas diffusion electrode components

- Proved that the electrolyte matrix thickness can be reduced to half of the baseline matrix thickness for improved performance without sacrificing the differential pressure capability

- Identified and developed electrode materials for the anode of the "without hydrogen" electrochemical CO2 removal cell

FY90 Activity

- Documentation of Phase I Results

- Initiation of Phase II Multi-cell Unit Design and Fabrication

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Supercritical Water Waste Oxidation

Objective

- **Expand the fundamental understanding of the SCWO waste treatment process**

- **Determine reaction mechanisms and effect of SCWO process variables (temperature, residence time, feed concentration, pressure) for simple compounds - methane, ammonia, etc.**

- **Determine mechanism of reaction residue (salt) formation - rate, temperature, etc.**

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Supercritical Water Waste Oxidation

Benefit

- System and crew waste approximately 6-8 lb/person-day (approximately 0.25 ft^3/person-day)

- SCWO process potentially

    - Reduces waste storage (35 ft^3 reduced to approximately 0.1 ft^3)

    - Produces excess water

        o Enhanced hygiene

        o Radiation protection supplement

        o EVA support

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Supercritical Water Waste Oxidation
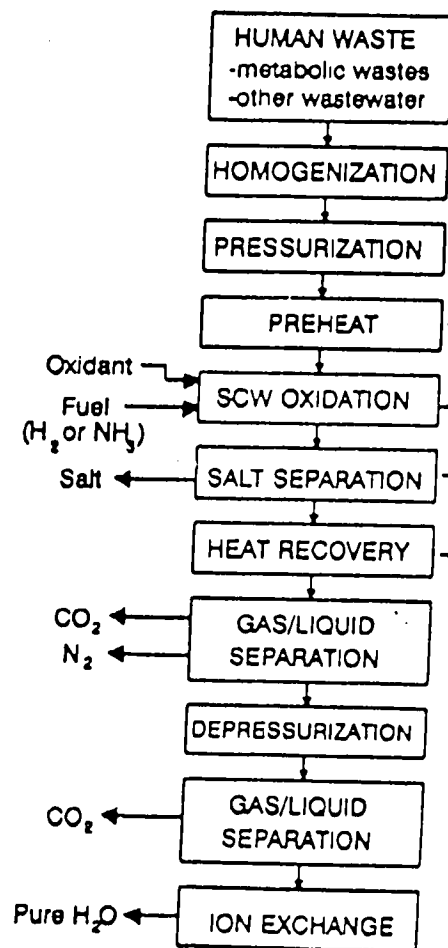
Technology Description

- SCWO process converts organic waste (feces, urine, trash) to carbon dioxide nitrogen, and water

- Process operation above the water critical point (3200 psia, 705 °F; 218 atm, 374 °C)

- Organic material is oxidized leaving reaction residue in the form of salts and oxides

- Process depends upon containment and removal of reaction ash

Status

- M.I.T. grant in final phase

  - September 1987 to September 1990

- Focus upon reaction kinetics and salt formation with analysis and experimental results

609

HUMAN WASTE TREATMENT AND RECYCLE
BY OXIDATION IN SUPERCRITICAL WATER (SCW)
(MODAR PROCESS)

PROCESS STEPS

MIT FUNDAMENTAL RESEARCH

HUMAN WASTE
-metabolic wastes
-other wastewater

↓

HOMOGENIZATION

↓

PRESSURIZATION

↓

PREHEAT

Oxidant →
Fuel →
(H_2 or NH_3) → **SCW OXIDATION**

Salt ← **SALT SEPARATION**

↓

HEAT RECOVERY

↓

CO_2 ←
N_2 ← **GAS/LIQUID SEPARATION**

↓

DEPRESSURIZATION

↓

CO_2 ← **GAS/LIQUID SEPARATION**

↓

Pure H_2O ← **ION EXCHANGE**

KINETIC STUDIES

Oxidation of model compounds
-Ammonia
-Hydrocarbons
-Alcohols
-Mixtures

Global kinetic models

Elementary reaction models

SALT STUDIES

Nucleation and Growth Kinetics

Solubility of salts in SCW
-Sodium Chloride
-Mixed salts

"In situ" Light Scattering Expts.
-High Pressure and
Temperature Optical Cell

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Supercritical Water Waste Oxidation

Results

- **Reaction kinetics**

    - Expanded experimentsal capability to 700 °C, 300 atm

    - Measurement of kinetics and correlation to analytical models for carbon monoxide, ethanol, methanol, methane, ammonia, ammonia/ethanol, carbon monoxide/ethanol

- **Salt formation**

    - Completed test apparatus assembly and initial checkout with water

    - Initiated preliminary sodium chloride experiments

    - Progressing with numerical modeling of salt mixing and precipitation

FY90 Activity

- Complete salt nucleation and preciptiation experiments and modeling

- Expand kinetic database to examine pressure variation, alternate oxidants, dissolved salts, heat transfer rate

611

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ELECTROOXIDATION FOR POST-TREATMENT OF RECLAIMED WATER

OBJECTIVE

- DEMONSTRATE FEASIBILITY OF ELECTROOXIDATION TECHNIQUE FOR POST-TREATMENT OF RECLAIMED WASTE WATERS (DISTILLATES, PERMEATES AND HUMIDITY CONDENSATES) FOR POTABLE AND HYGIENE USAGE

612

BENEFITS

- NEW COMPETING TECHNOLOGY FOR PURIFYING RECLAIMED WASTE WATERS

- NO EXPENDABLES

- REMOVES TOTAL ORGANIC IMPURITIES TO < 500 PPB

- SHOWS POTENTIAL FOR PROVIDING DISINFECTION

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ELECTROOXIDATION FOR POST-TREATMENT OF RECLAIMED WATER

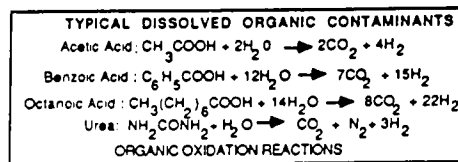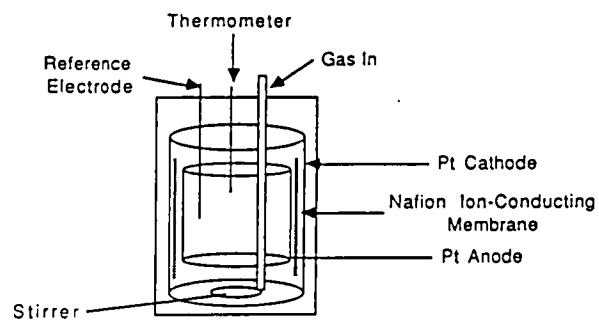## TECHNICAL DESCRIPTION

- ELECTROCHEMICAL CELL PROVIDES GENERATION OF STRONG OXIDIZING RADICALS (HO·)

- LIQUID ELECTROLYTE (0.7 M SODIUM PERCHLORATE)

- 170 W-HR REQUIRED TO OXIDIZE 50 PPM OF ORGANIC IMPURITY TO < 500 PPB IN 1 LITER OF WATER

- NO MOVING PARTS

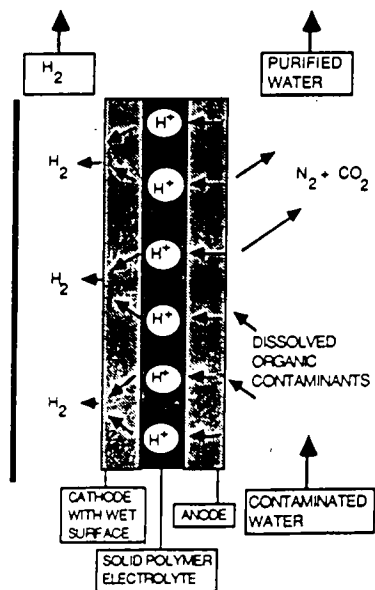## STATUS

- GRANT INITIATED WITH TAMU IN APRIL 1989

- EVALUATING FEASIBILITY OF CONCEPT AND OBTAINING PARAMETRIC DATA FOR DESIGN AND FABRICATION OF A BREADBOARD SYSTEM

- COMPLETION OF RESEARCH GRANT IN APRIL 1990

613

ELECTROLYSIS TEST CELL: INCORPORATING AN ION-CONDUCTING MEMBRANE

TYPICAL DISSOLVED ORGANIC CONTAMINANTS

Acetic Acid: $CH_3COOH + 2H_2O \rightarrow 2CO_2 + 4H_2$

Benzoic Acid: $C_6H_5COOH + 12H_2O \rightarrow 7CO_2 + 15H_2$

Octanoic Acid: $CH_3(CH_2)_6COOH + 14H_2O \rightarrow 8CO_2 + 22H_2$

Urea: $NH_2CONH_2 + H_2O \rightarrow CO_2 + N_2 + 3H_2$

ORGANIC OXIDATION REACTIONS

SCHEMATIC OF ELECTROCHEMICAL WATER POST-TREATMENT UNIT

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ELECTROOXIDATION FOR POSTREATMENT OF RECLAIMED WATER

FUTURE PLANS

- DEVELOP A BREADBOARD SYSTEM USING A SOLID POLYMER ELECTROLYTE FROM FUEL CELL TECHNOLOGY

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PHOTOCATALYTIC POST-TREATMENT OF RECLAIMED WATER

OBJECTIVE

- DEVELOP A BREADBOARD PHOTOCATALYTIC SYSTEM FOR POST-TREATMENT OF RECLAIMED WASTE WATERS (DISTILLATES, PERMEATES AND HUMIDITY CONDENSATE) FOR POTABLE AND HYGIENE USAGE

BENEFITS

- NEW COMPETING TECHNOLOGY FOR PURIFYING RECLAIMED WASTE WATERS

- REMOVES ORGANIC IMPURITIES TO LEVELS < 500 PPB

- PROVIDES DISINFECTION

- NO EXPENDABLES

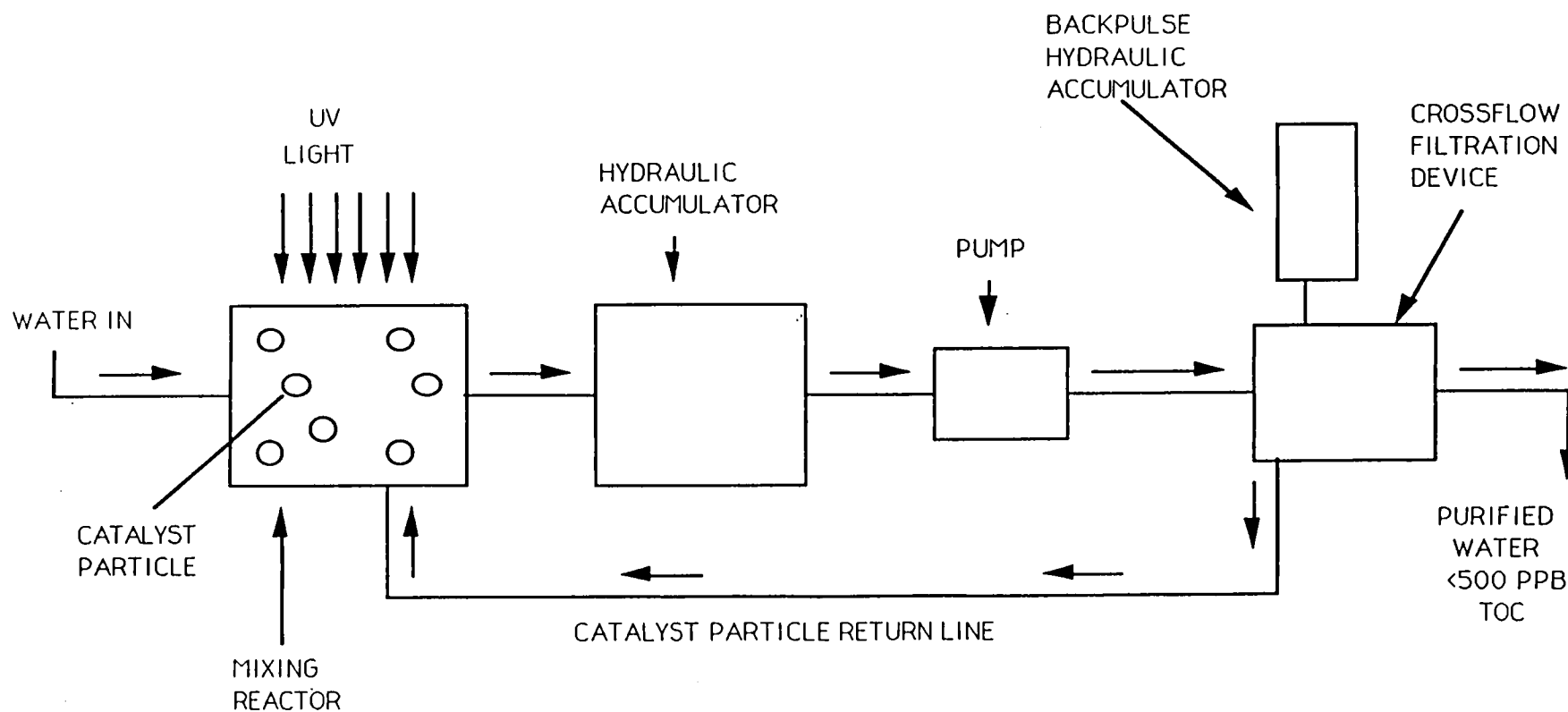| Technology for Space Station Evolution Workshop	Crew and Thermal Systems Division	
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PHOTOCATALYTIC POST-TREATMENT OF RECLAIMED WATERS

TECHNOLOGY DESCRIPTION

- ORGANIC IMPURITIES IN WATER ARE OXIDIZED BY POWERFUL OXIDIZING HYDROXAL RADICALS (OH•) AND HOLES (h +) PRODUCED WITH THE COMBINATION OF FINE METAL OXIDE CATALYST PARTICLES DISPERSED IN WATER WITH UV LIGHT AND DISSOLVED O2

- BATCH SYSTEM PROCESSES 12 LITERS OF WATER EVERY 2 HOURS

- SEPARATES CATALYST PARTICLES BY CROSS-FILTRATION THROUGH MICROPOROUS MEMBRANE

- RECOVERS PARTICLES FOR REUSE BY BACKFLUSHING OF MEMBRANE

- OPERATES CLOSE TO AMBIENT TEMPERATURE (35 ° C)

617

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SCHEMATIC OF PHOTOCATALYTIC
BATCH REACTOR POST-TREATMENT SYSTEM

618

UV
LIGHT

BACKPULSE
HYDRAULIC
ACCUMULATOR

CROSSFLOW
FILTRATION
DEVICE

HYDRAULIC
ACCUMULATOR

PUMP

WATER IN

CATALYST
PARTICLE

MIXING
REACTOR

CATALYST PARTICLE RETURN LINE

PURIFIED
WATER
<500 PPB
TOC

POST-TREATMENT SYSTEM PROCESSES
12 LITERS PURIFIED WATER PER HOUR

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PHOTOCTALYTIC POST-TREATMENT OF RECLAIMED WATER

STATUS

- PHASE II SBIR WITH PHOTOCATALYTICS, INC. BOULDER, CO INITIATED IN APRIL 1987

- BREADBOARD SYSTEM IN FABRICATION AND SCHEDULED FOR COMPLETION FEBRUARY

FY 90 ACTIVITY

- TEST BREADBOARD SYSTEM WITH RECLAIMED WASTE WATERS TO DEMONSTRATE PERFORMANCE FOR

    - REMOVAL OF ORGANIC IMPURITIES TO < 500 PPB

    - DISINFECTION FROM 10 EXP 7 CFU TO O MICROORGANISMS

- CONTRACT COMPLETION IS APRIL 1990

FUTURE PLANS

- CONTINUE TECHNOLOGY DEVELOPMENT

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